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DOCUMENTATION AND DESCRIPTION OF THE BENT IONOSPHERIC MODEL

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13. ABSTRACT

This report documents the computer programs of the Bent Ionospheric Model and briefly describes the development of the model. The FORTRAN Program is designed for general use and can generate ionospheric data on a world-wide basis for any past or future date. For a given condition consisting of station, satellite and time information, the electron density versus height profile is computed from which range, range rate, and angular refraction corrections as well as vertical and angular total electron content are obtained. The model has the additional capability of improving its predictions by updating with actual ionospheric observations. Considerable tests in the past have proved this empirical model highly successful. Also included in the documentation is an alternate version of the ionospheric program to be used when stringent space and time requirements are imposed by the operating system. However, several options of the standard program are not incorporated and the accuracy of the results is somewhat reduced.

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FOREWORD

This document was prepared by Atlantic Science Corporation of Indialantic, Florida, for the Air Force Space & Missile Systems Organization (SAMSO), System 621B under Contract F04701-73-C-0207. This contract was jointly sponsored by funds from SAMSO and The Air Force Cambridge Research Laboratories. The document is assigned the USAF Report No. SAMSO TR-73-252.

Captain R. Collins and Major R.H. Jesson served as Project Officers of this program. Appreciation is also due to Mr. J. Klobuchar of AFCRL who closely monitored the progress of this contract.

The majority of the development of the model was funded by NASA/Goddard Space Flight Center and monitored by Mr. P. Schmid, Code 591. The remaining portion of the model development was funded by the Air Force Space & Missile Systems Organization (SAMSO), System 621B under Contract F04701-72-C-0380 and monitored by Capt. L.J. Plotkin and Major R.H. Jesson.

The principal investigations in this work as well as the earlier development were performed by Rodney B. Bent and Sigrid K. Llewellyn. Mrs. Llewellyn was totally responsible for the software development and implementation.

Publication of this report does not constitute approval of the reports findings or conclusions. It is published only for the exchange and stimulation of ideas.

B.W. Parkinson, Colonel, USAF

Deputy for Defense Navigation Satellite Systems

ABSTRACT

This report documents the computer programs used in the Bent Ionospheric Model and briefly describes the development of the model. The FORTRAN Program is designed for general use and can generate ionospheric data on a world-wide basis for any past or future date. For a given condition consisting of station, satellite and time information, the electron density versus height profile is computed from which range, range rate, and angular refraction corrections as well as vertical and angular total electron content are obtained. The model has the additional capability of improving its predictions by updating with actual ionospheric observations. Considerable tests in the past have proved this empirical model highly successful. Also included in the documentation is an alternate version of the ionospheric program to be used when stringent space and time requirements are imposed by the operating system. However, several options of the standard program are not incorporated and the accuracy of the results is somewhat reduced.

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GLOSSARY

A	Azimuth angle of measured ray path
E	Elevation angle of measured ray path
ΔE	Error in E due to refraction
$\dot{E}$	$\frac{dE}{dt}$, time derivative of the elevation angle
f_oF2	Critical frequency of the F2 layer
f	Wave frequency
h_m h_m F2	Height of maximum electron density of f_oF2 above surface of the earth
h_s	Height of satellite
$\dot{h}$	$\frac{dh_s}{dt}$, time derivative of satellite height
k_1 , k_2 , k_3	Decay constants of the lower, middle and upper topside exponential layer of the profile
M factor M(3000)F2	MUF(3000)F2/f_oF2
MUF(3000)F2	The maximum useable frequency to propagate (by reflection from F2) over 3000 km
N	Electron density at height h
N_m	Maximum electron density
N_T	The total electron content in a vertical direction
R_e	Mean radius of earth
ΔR	One way range correction
$\Delta\dot{R}$	One way range rate correction
y_m	Half thickness of bottomside bi-parabolic layer
y_t	Half thickness of topside parabolic layer
ϕ , λ	Latitude and longitude of the ionospheric point, where the wave passes through the densest part of the ionosphere
ϕ_s , λ_s	Station latitude and longitude

1.0 Scope

This specification establishes the requirements for complete identification of Items #0001 and 0002, "Documentation and Description of the Bent Ionospheric Model," to be formally accepted by the procuring activity.

The Bent Ionospheric Model is an empirical world-wide computerized alogrithm capable of predicting the ionospheric electron density profile and the associated delay and directional changes of a wave due to refraction. The following documentation of this model is formatted in accordance with Paragraph 60.5, computer program product specifications, MIL-STD-483, "Configuration Management Practices for Systems, Equipment, Munitions, and Computer Programs."

Sections 3.1 and 3.4 outline the overall program structure, Section 3.2 gives a detailed description of each program component, Sections 3.3 and 4.1 incorporate the program operation description, Section 6.1 and 6.2 outline the ionospheric model development and present its accuracy and limitations, and Appendix I contains the program listings.

2.0 Applicable Documents

The documents of exact issue shown, form a part of this specification to the extent specified herein. In case a conflict occurs between the referenced reports and the detailed content of sections 3, 4, 5, and 10, the detailed content shall be considered a superseding requirement for this CPCI.

References

1. E. V. Appleton & W. J. G. Beynon, Proc. Phys. Soc. 52, Pt. I, 518 (1940); Proc. Phys. Soc. 59, Pt. II, 58 (1947)
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3.0 Requirements - Technical Description

In the area of satellite communications the refraction incurred by a wave propagating through the ionosphere is most important. The Bent Ionospheric Model is an empirical world-wide algorithm capable of accurately estimating the electron density profile and the associated delay and directional changes of a wave due to refraction. The model computes the electron density versus height profile from which the range, range rate, and the angular refraction corrections for the wave are obtained as well as the vertical and angular total electron content. Although the model is presented for ground to satellite communications, it is readily adaptable for ground to ground, or satellite to satellite communications.

The only required inputs to the model are satellite and station position and time information and a limited amount of solar data. For the model's additional capability of improving the ionospheric predictions by use of actual ionospheric observations, measured values of electron content or the critical frequency of the F2 layer, foF2, can be incorporated along with the observation station and time information. This update option uses a weighted mean technique that can accept, for the update, several measurements from different stations separated in time and space from the time and location at which the ionosphere is to be evaluated.

The updating process is generally used for predicting ionospheric conditions or refraction corrections after the fact, when observations are generally available. However, the model's prediction accuracy without update accounts for approximately 75 to 80 percent of the ionosphere which can improve with update to approximately 90 percent. The model, therefore, may be applied for future predictions or after the fact calculations. Since the model has been developed on a world-wide basis, predictions are not limited to any particular land mass or segment of the world. The updating technique does, however, require that ionospheric observations be from stations within 2000 km radius of the evaluation site. The model is applicable for determining

wave refraction and ionospheric characteristics up to 2000 km in height and for all radio wave frequencies as long as the vertical component is slightly higher than critical frequency.

Built into the model are the combined influences of geographical and geomagnetic effects, solar activity, local time, and seasonal variations. These combined effects are the results of an extensive investigation of a vast ionospheric data base that included over 50,000 topside soundings, 6,000 satellite measurements of electron density and related foF2, and over 400,000 bottomside soundings. The data base, which formed the basis of the model, extended over the period of 1962 to 1969, covering the minimum to maximum of a solar cycle. For further information regarding the development and evaluation of the Bent Ionospheric Model, see Reference 2 and Section 6.0.

3.1 Functional Allocation Description

The ionospheric PROGRAM ION is written in FORTRAN IV code and has a simple load structure with no overlay requirements. The following program/subroutines comprise the CPCI, and the attached diagram identifies the calling routines and the subprograms called for each computer program component;

CPCs : PROGRAM ION, and SUBROUTINES REFRAC, PLOTNH, PROFL1, PROFL2, BETA, SICOJT, DKSICO, MAGFIN, GK, DKGK.

The following library subprograms are required :

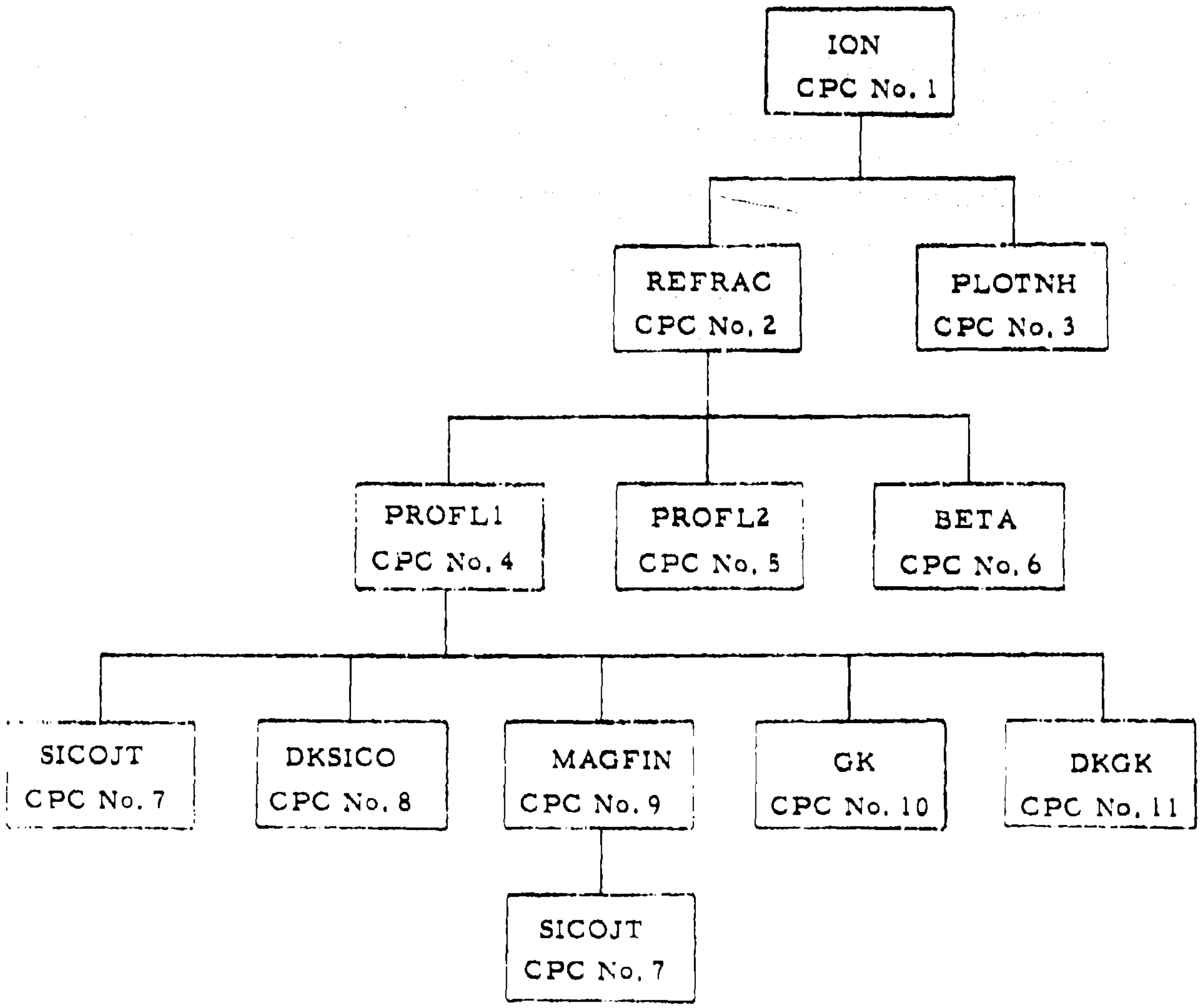
ABS, AMOD, ATAN, COS, EXP, LOG10, SIGN, SIN, SQRT.

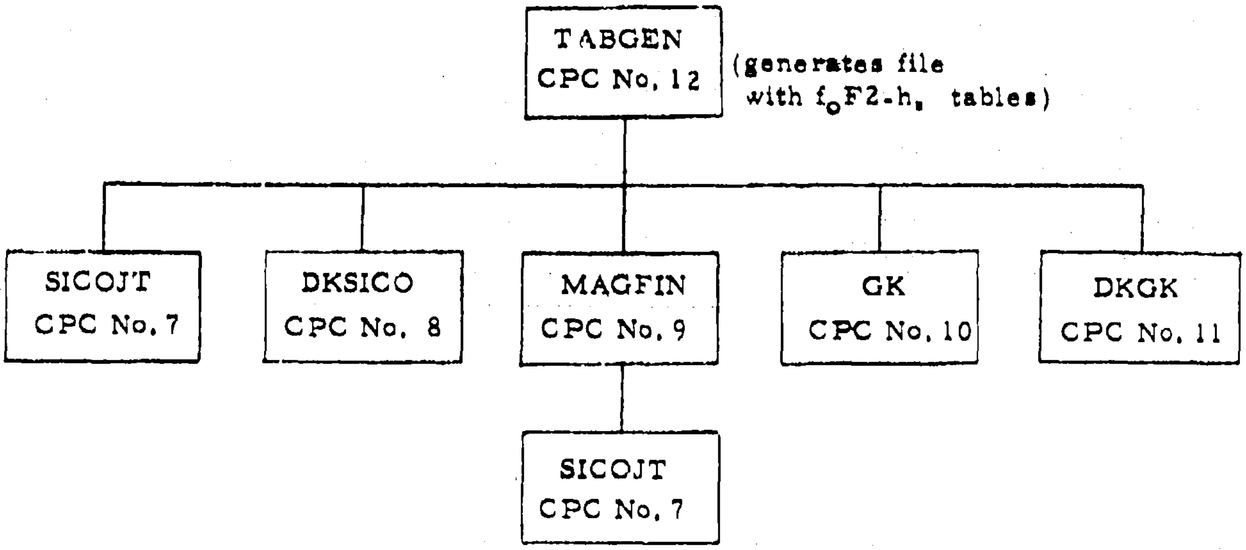
All internal data transfer between the individual CPCs occurs through labeled common blocks and through the calling sequences, which are both described under Section 3.2.1.3 for each CPC. The external data transfer consists of input coming from the data card deck into PROGRAM ION and from the ionospheric coefficient data tape into SUBROUTINE REFRAC, and of output of the results from PROGRAM ION and SUBROUTINE PLOTNH to the line printer; these files are described in detail in Section 3.3.1. The functions performed by the program are described in Section 3.4 and referenced to the CPCs to which they are assigned.

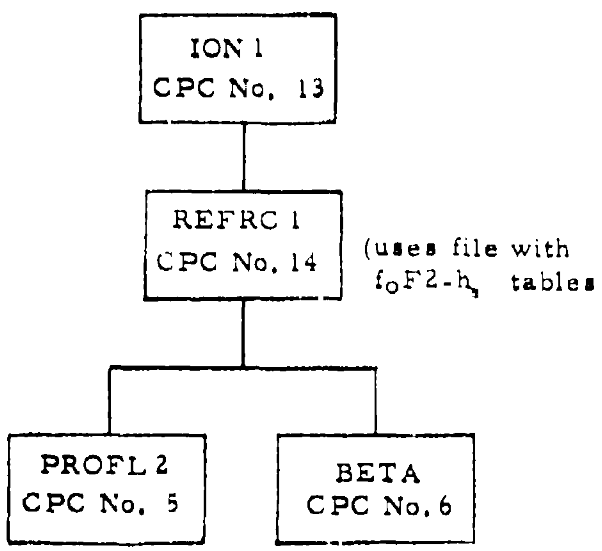
An alternate version of the ionospheric program is included in this documentation, consisting of a preprocessor TABGEN and a reduction program ION1. Both programs are written in FORTRAN IV code, have a simple load structure with no overlay requirements, are run as separate entities, and are only linked by the data file (disc or tape) produced by the preprocessor and utilized in ION1. PROGRAM TABGEN requires the following SUBROUTINES SICOJT, DKSICO, MAGFIN, GK, DKGK, and the library functions AMOD, ATAN, COS, SIN, SQRT. All internal data transfer occurs through the calling sequences; the external data transfer consists of input coming from the data card deck and the ionospheric coefficient tape and of output of f_oF2-h_s tables to disc or tape, all in PROGRAM TABGEN. PROGRAM ION1 requires the

following SUBROUTINES REFRC1, PROFL2, BETA and the library functions ABS, AMOD, ATAN, COS, FLOAT, SIN, SQRT. All internal data transfer occurs through the labeled common blocks and through the calling sequences. The external data transfer consists of input coming from the data card deck into ION1, from the preprocessed disc or tape file with f_oF2-h_s tables into SUBROUTINE REFRC1, and of output of the results from PROGRAM ION1 to the line printer. The second attached diagram shows the program structures, the data files are described in Section 3.3.1, and the functions performed by the preprocessor and reduction program are outlined in Section 3.4.

Whenever ionospheric predictions are desired, PROGRAM ION should have preference over the program set TABGEN-ION1. ION will yield more accurate results than ION1 where approximations are introduced through interpolating the f_oF2-h_s tables and through bypassing the iteration on the height estimate of the ionosphere. ION also has the additional features not included in ION1 of computing range rate corrections for range differencing, of plotting the ionospheric profile, and of updating the predictions with actual ionospheric observations. For many applications ION will be suited even for real-time processing. The program set TABGEN-ION1 should only be used when stringent core space and/or run time requirements are imposed that cannot be met by PROGRAM ION, or when program modifications for special applications are attempted. Running PROGRAM TABGEN in a preprocessing mode results in the significant core space and run time reduction of PROGRAM ION1.


ION
CPC No. 1
REFRAC
CPC No. 2
PLOTNH
CPC No. 3
PROFL1
CPC No. 4
PROFL2
CPC No. 5
BETA
CPC No. 6
SICOJT
CPC No. 7
DKSICO
CPC No. 8
MAGFIN
CPC No. 9
GK
CPC No. 10
DKGK
CPC No. 11
SICOJT
CPC No. 7


TABGEN
CPC No. 12
(generates file
with f_oF2-h_s tables)
SICOJT
CPC No. 7
DKSICO
CPC No. 8
MAGFIN
CPC No. 9
GK
CPC No. 10
DKGK
CPC No. 11
SICOJT
CPC No. 7


ION 1
CPC No. 13
REFRC 1
CPC No. 14
(uses file with
f_oF2-h_s tables)
PROFL 2
CPC No. 5
BETA
CPC No. 6

3.2 Functional Description

This paragraph contains the detailed technical descriptions of the computer program components identified in Paragraph 3.1 of this specification. The instruction listings contained in Appendix I specify the exact configuration of the Bent Ionospheric Program ION and the alternate version TABGEN - ION1.

Following are specifically the descriptions for:

CPC No. 1	-	PROGRAM ION
CPC No. 2	-	SUBROUTINE REFRAC
CPC No. 3	-	SUBROUTINE PLOTNH
CPC No. 4	-	SUBROUTINE PROFL1
CPC No. 5	-	SUBROUTINE PROFL2
CPC No. 6	-	SUBROUTINE BETA
CPC No. 7	-	SUBROUTINE SICOJT
CPC No. 8	-	SUBROUTINE DKSICO
CPC No. 9	-	SUBROUTINE MAGFIN
CPC No. 10	-	SUBROUTINE GK
CPC No. 11	-	SUBROUTINE DKGK

Particular to all subroutines is the fact that none of the input variables transferred through common or the calling sequences are modified during excution of the program code. The units internal to all subroutines are kept in meters for distances, radians for angles and times, meters/second for linear velocities, radians/second for angular rates, MHz for frequencies and Gauss for magnetic field strength.

Included are also the descriptions of the routines that are required in addition ot the ones listed above for the alternate version of the ionospheric program, consisting of separate preprocessor and reduction programs:

CPC No. 12	-	PROGRAM TABGEN
CPC No. 13	-	PROGRAM ION1
CPC No. 14	-	SUBROUTINE REFRC1

3.2.1 Computer Program Component 1

CPC No. 1, main PROGRAM ION, is written in FORTRAN code. It handles the card input and the printing of the results for the entire program, except for the list and plot of the profile which is done by SUBROUTINE PLOTNH upon call from ION. ION transfers the input conditions through commons /EVAL/ and/UPDT/ and by calling SUBROUTINE REFRAC receives the computed profile parameters and refraction corrections through common/CORR/.

3.2.1.1 CPC No. 1 Description

ION reads the selections for the output and update options from cards, it reads the station, satellite and time information for the condition to be evaluated, and as needed, reads the solar data from cards. If the option for updating the predictions with measured ionospheric data was chosen, the number of observations to be used for the update and the corresponding observation along with station and time information are read from cards. Up to eight measurements can be used simultaneously for updating any one evaluation condition. All input data is listed for reference in the print out.

The input data is converted to the internal units of meters for distances and radians for angles and times. The variables specifying the evaluation condition are transferred through common/EVAL/, the update conditions through common/UPDT/to SUBROUTINE REFRAC. Through REFRAC and other routines called by REFRAC ionospheric profile parameters, vertical and angular electron content, refraction corrections to elevation angle, range, and instantaneous range rate are computed as desired and returned to ION through common/CORR/. ION prints the results as requested and calls SUBROUTINE PLOTNH for an electron density profile plot and list, whenthis type of output is specified.

If the refraction correction to range rate, obtained by range differencing over a finite time during which the ionosphere can undergo changes, is requested, the input for the evaluation condition above relates to the first range observation, and additional satellite and time information that is read from card relates to the last range observation used in the differencing technique. Upon return the

second range correction from REFRAC, ION computes the requested ... correction by differencing the two range corrections and dividing by th... interval; the result is printed.

Any number of evaluation conditions can be processed by supplying additional input data and repeating the program steps outlined above. For more details about the input data and output options refer to the input data description under 3.3.1.

3.2.1.2 CPC No. 1 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 1 Interfaces

a) Library subprograms required: none

b) Other subprograms called: SUBROUTINES REFRAC, PLOTNH

c) Calling program: none

d) Calling sequence: PROGRAM ION

e) Common blocks: EVAL, UPDT, CORR

Variables in common:

See description for EVAL, UPDT, CORR under SUBROUTINE REFRAC, CPC No. 2.

f) File requirements: card reader, line printer

The requirements for the input data card file are specified under 3.3.1.

3.2.1.4 CPC No. 1 Data Organization

Variables defined in data statements:

Name	Dimension	Description
LYRMO	1	= 0, initialization constant for (year×100+month)
IDRD	1	= 0, default condition: range rate correction for observation over finite time is not desired
IOPT	1	= 1, default condition: computation of critical frequency and corresponding height is desired

Name	Dimension	Description
MEAS	5 x 3	Array containing hollerith data for print out

Other constants defined in data statement:

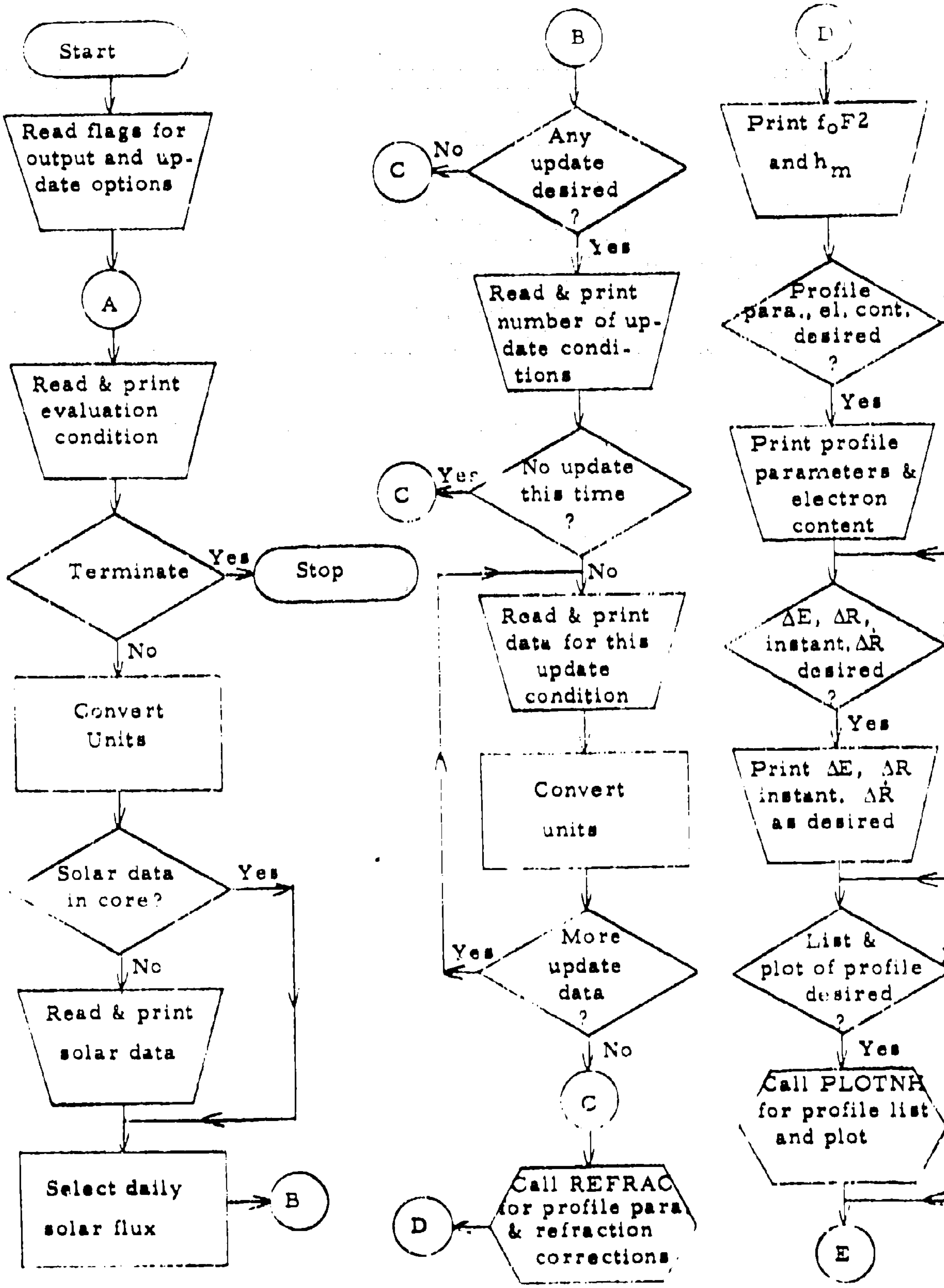
QO=0, Q1000=1000, Q3600=3600; DR=1°, HR=1 hour, PI2=360° converted to radians. Important variables are described under 3.2.1.3 e) of SUBROUTINE REFRAC, CPC No. 2.

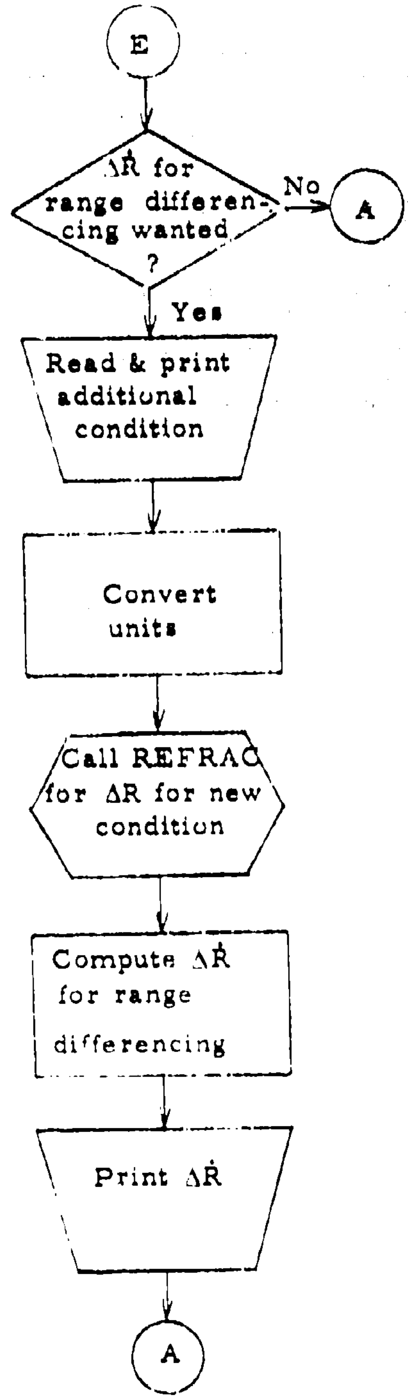
3.2.1.5 CPC No. 1 Limitations

Up to eight measurement entries can be used simultaneously for updating the predictions for any one evaluation condition. If update with more than eight conditions is requested, the program uses the first eight entries, ignores any additional input data and prints a message to that effect.

Error tests on the sequence, units and formats of the input data are not performed, except on the dates of the solar data cards. However, mistakes in the set up of the card deck are revealed in the printout of the input data that is listed along with the results.

CPC No. 1 Flowchart, PROGRAM ION




E
ΔṘ for range differencing wanted ?
No
A
Yes
Read & print additional condition
Convert units
Call REFRAC for ΔR for new condition
Compute ΔṘ for range differencing
Print ΔṘ
A

3.2.1 Computer Program Component 2

CPC No. 2, SUBROUTINE REFRAC, is written in FORTRAN code and is called from the main PROGRAM ION. REFRAC prepares the coefficient and solar input data, it obtains the ionospheric profile parameters via PROFL1 and PROFL2, it performs an optional update using up to eight observation entries, it computes the ionospheric refraction corrections ΔR for range, $\Delta\dot{R}$ for instantaneous range rate and obtains the refraction correction ΔE for the elevation angle via LETA.

3.2.1.1 CPC No. 2 Description

REFRAC prepares the coefficients to be used in SUBROUTINE DKSICO for the computation of the time dependent coefficients which in turn are required for the computation of critical frequency f_oF2 and M(3000)F2. At first it is checked if the coefficients are already available for the desired date, and if not available, the proper coefficients are read from tape. These general coefficients are valid for any condition and do not have to be updated or replaced, but can be adjusted for any time in the past or future.

The general f_oF2 coefficients were derived using the work of Jones and Obitts (Reference 6); they provide annual continuity and are valid for approximate 10 day periods, for the spans from day 1 to 10, day 11 to 20, and day 21 to 30 (or 28, 29, 31) of each month. There are coefficients for 36 periods to cover the whole year. The general f_oF2 coefficients $W_{j,i,k}$ represent the coefficients to a second order polynomial in the 12-month running average of solar flux F_{12} (observed Ottowa 10.7 cm solar flux). They are evaluated for the specific F_{12} of the evaluation date to yield the specific f_oF2 coefficient set $U_{i,k}$ (stored in array U) used in SUBROUTINE DKSICO;

$$U_{i,k} = W_{1,i,k} + W_{2,i,k} \times F_{12} + W_{3,i,k} \times F_{12}^2 \quad , \text{ for } i = 0,1,\ldots 12 \text{ and } k = 0,1,\ldots.75.$$

The general M(3000)F2 coefficients available from NOAA, Boulder, are valid for monthly periods. There are coefficents for 12 periods to cover the whole year, and for each period there are two sets $V_{i,k}(0)$ and $V_{i,k}(100)$, one for a 12-month running average of sunspot number $S_{12} = 0$ and the other for $S_{12} = 100$. The coefficients are adjusted by interpolating or extrapolating the two sets to the specific S_{12} of the evaluation date yielding the specific M(3000)F2 coefficient set $U_{i,k}$ (stored in array UM) used in SUBROUTINE DKSICO;

$$U_{i,k} = V_{i,k}(0) + \left[V_{i,k}(100) - V_{i,k}(0)\right] \times \frac{S_{12}}{100}, \text{ for } i = 0, 1, \ldots, 8 \text{ and}$$

$$k = 0, 1, \ldots, 48.$$

The 10.7 cm Ottowa solar flux data is prepared for use in SUBROUTINES PROFL1 and PROFL2. The difference ΔF between the daily value F and the 12-month running average of the solar flux is formed, $\Delta F = F - F_{12}$. If the daily solar flux is not available, F_{12} is substituted. If the daily solar flux is greater than 130, 130 is substituted which is a limit imposed by the data base on which development of the model was founded.

The first parameters for the ionospheric profile, the critical frequency f_oF2 and the corresponding height h_s are obtained via SUBROUTINE PROFL1.

On option REFRAC updates the predicted f_oF2 with observations of f_oF2 or with vertical or angular electron content reduced from Faraday rotation measurements from other stations. Up to eight update observations of either type separated by different amounts in time and space from the evaluation time and station can be accepted. To obtain the best possible update, the observation times and stations should be the closest to the evaluation condition available, in any case, the update station should be within 2000 km of the evaluation site.

If the observation is angular electron content N_{TA}, it is reduced to total vertical electron content N_T by,

$$N_T = N_{TA} \sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_s}\right)^2},$$

E being the elevation angle of the observation, and R_e the mean earth radius. For each update observation the predicted f_oF2 is obtained by calling SUBROUTINE PROFL1, and the update ratio r is formed for f_oF2 observations,

$$r = \frac{f_oF2 \text{ obs.}}{f_oF2 \text{ pred.}}$$

If the observation is electron content, the additional profile parameter N_T/N_m is obtained via SUBROUTINE PROFL2, and the following ratio is formed,

$$r = \sqrt{\frac{N_T \text{ obs.}}{1.24 \times 10^{10} f_oF2^2 \text{pred.} \left(\frac{N_T}{N_m}\right)\text{pred.}}}, \text{ where } f_oF2 \text{ is in MHz}$$

and since the maximum electron density is $N_m = 1.24 \times 10^{10} f_oF2^2$, and N_T is approximately proportional to f_oF2^2, the electron content information is reduced to a f_oF2 ratio,

$$r = \sqrt{\frac{N_T \text{ obs.}}{N_T \text{ pred.}}} \approx \frac{f_oF2 \text{ obs.}}{f_oF2 \text{ pred.}}$$

If there is only one update condition, the ratio r is used for the final ratio R to update f_oF2. If several n conditions are used for the update, a weighted mean technique combines all n ratios r_i to the final ratio R having as weights w_i the time differences Δt_i between observation and evaluation times and/or the earth central angles α_i between the ionospheric points at which the rays from the observation and evaluation stations pass through the ionosphere,

$$R = \frac{\sum_{i=1}^{n} \frac{r_i}{w_i}}{\sum_{i=1}^{n} \frac{1}{w_i}},$$

$w_i = \Delta t_i$, if observations are from one station at different times,

$w_i = \alpha_i$, if observations are from several stations at the same time,

$w_i = \Delta t_i \alpha_i$, if observations are from several stations at different times.

$$\Delta t = |t - t_0| \quad \text{and}$$

$$\cos \alpha = \sin\phi \sin\phi_0 + \cos\phi \cos\phi_0 \cos(\lambda - \lambda_0),$$

where t, ϕ, λ and t_0, ϕ_0, λ_0 are the time, latitude and longitude of the ionospheric points for evaluation and observation condition respectively. The final ratio R updates the critical frequency by the same overall percentage by which the predictions deviate from the ionospheric observations,

$$f_oF2\ \text{upd.} = f_oF2\ \text{pred.} \times R\ .$$

By calling SUBROUTINE PROFL2 the remaining profile parameters are obtained: y_m the half thickness of the bottomside bi-parabolic layer, y_t the half thickness of the topside parabolic layer, k_1, k_2, k_3 the decay constants for the lower, middle, and upper section of the topside exponential layer, N_T/N_m the ratio of the total integrated electron content to the maximum electron density, m the multiplier of the $\dot{h}$, rate of change in height, term in the range rate equation.

The one-way ionospheric refraction correction ΔE to the elevation angle E is calculated via SUBROUTINE BETA. The total integrated electron content N_T along a vertical path through the ionosphere and the angular content along the line of sight N_{TA} are computed as:

$$N_T = 1.24 \times 10^{10}\ f_oF2^2 \left(\frac{N_T}{N_m}\right), \quad N_{TA} = \frac{N_T}{\sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_m}\right)^2}} \ .$$

The one-way ionospheric refraction correction to range ΔR is given by the equation

$$\Delta R = \frac{40.3 \times 10^{-12} N_T}{f^2 \sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_m}\right)^2}} = \frac{40.3 \times 1.24 \times 10^{-2}}{\sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_m}\right)^2}} \left(\frac{f_oF2}{f}\right)^2 \frac{N_T}{N_m}$$

where f is the transmission frequency, $\frac{1}{f^2} = \frac{1}{2}\left(\frac{1}{f_u^2} + \frac{1}{f_d^2}\right)$ f_u and f_d are uplink and downlink frequencies.

The one-way ionospheric refraction correction to range rate $\Delta\dot{R}$ consists of two terms, one multiplied by the altitude rate $\dot{h}$, the other by the elevation rate $\dot{E}$;

$$\Delta\dot{R} = -\frac{40.3 \times 1.24 \times 10^{-6}}{\sqrt{1-\left(\frac{R_e \cos E}{R_e+h_s}\right)^2}} \left(\frac{f_oF2}{f}\right)^2 m\,\dot{h} + \frac{\Delta R\left(\frac{R_e}{R_e+h_s}\right)^2 \sin E \cos E}{1-\left(\frac{R_e \cos E}{R_e+h_s}\right)^2}\,\dot{E}$$

This range rate correction formulation applies only to instantaneous range rate measurements, since it assumes that the only variation in the total electron content over the time of the observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant for the duration of the measurement. Corrections to range differencing are discussed under 3.2.1.5.

The signs of the refraction corrections are set for the corrections to be subtracted from their respective observations. The units in all equations above are kept in meters, meters/second, radians, radians/second and MHz.

3.2.1.2 CPC No. 2 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 2 Interfaces

a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT

b) Other subprograms called: SUBROUTINES PROFL1, PROFL2, BETA

c) Calling programs: PROGRAM ION

d) Calling sequence: SUBROUTINE REFRAC

e) Common blocks: EVAL, UPDT, CORR

Variables in common:

Common Name	Variable Name	Dimension	I/O	Description
EVAL	FS	1	I	Transmission frequency (MHz)
EVAL	FLAT	1	I	Latitude of station (radians)
EVAL	FLON	1	I	Longitude of station (radians)
EVAL	ELEV	1	I	Elevation to satellite (radians)

Common Name	Variable Name	Dimension	I/O	Description
EVAL	AZ	1	I	Azimuth to satellite (radians)
EVAL	HS	1	I	Height of satellite (m)
EVAL	EDOT	1	I	Elevation rate (radians/sec)
EVAL	HDOT	1	I	Altitude rate (m/sec)
EVAL	TIME	1	I	Universal time (radians)
EVAL	FLXD	1	I	Daily solar flux
EVAL	SIS	1	I	12-month running average of sun-spot number
EVAL	SIF	1	I	12-month running average of solar flux
EVAL	IYR	1	I	Year (last 2 digits)
EVAL	MON	1	I	Month (=1 through 12)
EVAL	IDAY	1	I	Day (=1 through 31)
EVAL	IOPT	1	I	Control constant for optional computations: =1 to compute f_oF2 and h_m, =2 to also compute remaining profile parameters and electron content, =3 to compute ΔR in addition, =4 to also compute $\Delta\dot{R}$
EVAL	IDEL	1	I	Control constant to compute ΔE besides profile parameters and electon content, =0 compute, =1 not
EVAL	IDRD	1	I	Flag to eliminate unnecessary computations during calculation of the second range correction used in the differencing for the range rate correction, =0 for first, =1 for second calculation
EVAL	IUPDT	1	I	Update flag, =0 no update, =1 update
EVAL	ITP	1	I	Unit assignment of general ionospheric coefficient tape
UPDT	ULAT	8	I	Latitudes of update stations (radians)
UPDT	ULON	8	I	Longitudes of update stations (radians)
UPDT	ULEV	8	I	Elevation angles of observations (radians)

Common Name	Variable Name	Dimension	I/O	Description
UPDT	UZIM	8	I	Azimuth angles of observations (radians)
UPDT	UT	8	I	Universal time of observations (radians)
UPDT	OBS	8	I	Observation of f_oF2, vertical or angular electron content (MHz or electrons/m^2)
UPDT	ITYP	8	I	Observation type, =1 for f_oF2, =2 for vertical, =3 for angular electron content
UPDT	NUPDT	1	I	Number of update conditions
CORR	DRANG	1	O	Range correction (m)
CORR	DRATE	1	O	Range rate correction (m/sec)
CORR	DELEV	1	O	Elevation angle correction (radians)
CORR	F0F2	1	O	Critical frequency (MHz)
CORR	HM	1	O	Height at maximum electron density (meters)
CORR	YM	1	O	Half thickness of the bottomside bi-parabolic layer (meters)
CORR	YT	1	O	Half thickness of the topside parabolic layer (meters)
CORR	XK	3	O	Decay constants of lower, middle and upper section of the exponential top-side layer (1/meter)
CORR	TOTN	1	O	Total vertical electron content (e/m^2 column)
CORR	TOTNA	1	O	Total angular electron content (e/m^2 column)

f) File requirements: general coefficient input tape, line printer

The format of the general coefficient tape is described under 3.3.1.

3.2.1.4 CPC No. 2 Data Organization

Variables defined in data statements:

Name	Dimension	Description
R	1	Mean earth radius (meters)
STRS	1	Approximate height of stationary satellite used when updating with observed electron content (meters)
TOL	1	Tolerance for differences in positions or observation times of multiple update stations below which they are assumed to be identical (radians)
MONDY	1	Initialization constants for last and first (month x 100 + day) for which coefficients are in core
MOND	1	
LYRMO	1	Initialization constant for (year x 100 + month)

Other constants defined in data statements:

QO=0, Q1=1, Q100=100, Q130=130, QP1=.1, QNM=1.24×10^{10}, RN3=.49972;

PI=180°, PI2=360° converted to radians.

Other important variables are described under 3.2.1.3 e).

3.2.1.5 CPC No. 2 Limitations

The daily value of solar flux transferred to SUBROUTINE PROFL2 for the computation of the decay constants for the topside exponential profile is truncated at a maximum value of 130. This is the boundary that was imposed by the data base during the model development and is thus a limit to the model since the extension of solar flux beyond 130 could result in invalid profiles.

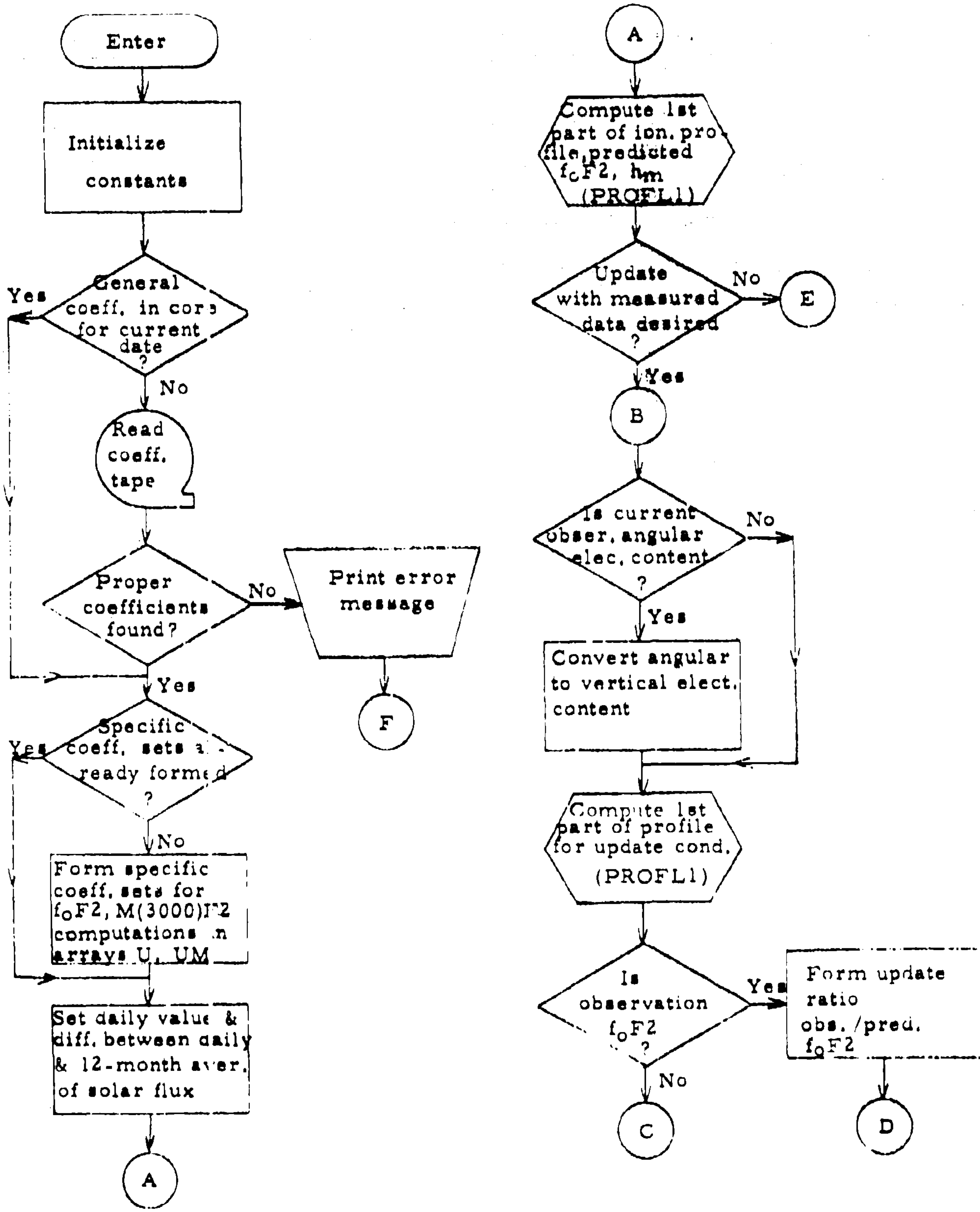
The dimensions of several arrays restrict the update procedure to be applied to the predictions of any one evaluation condition, to not include more than eight observation entries.

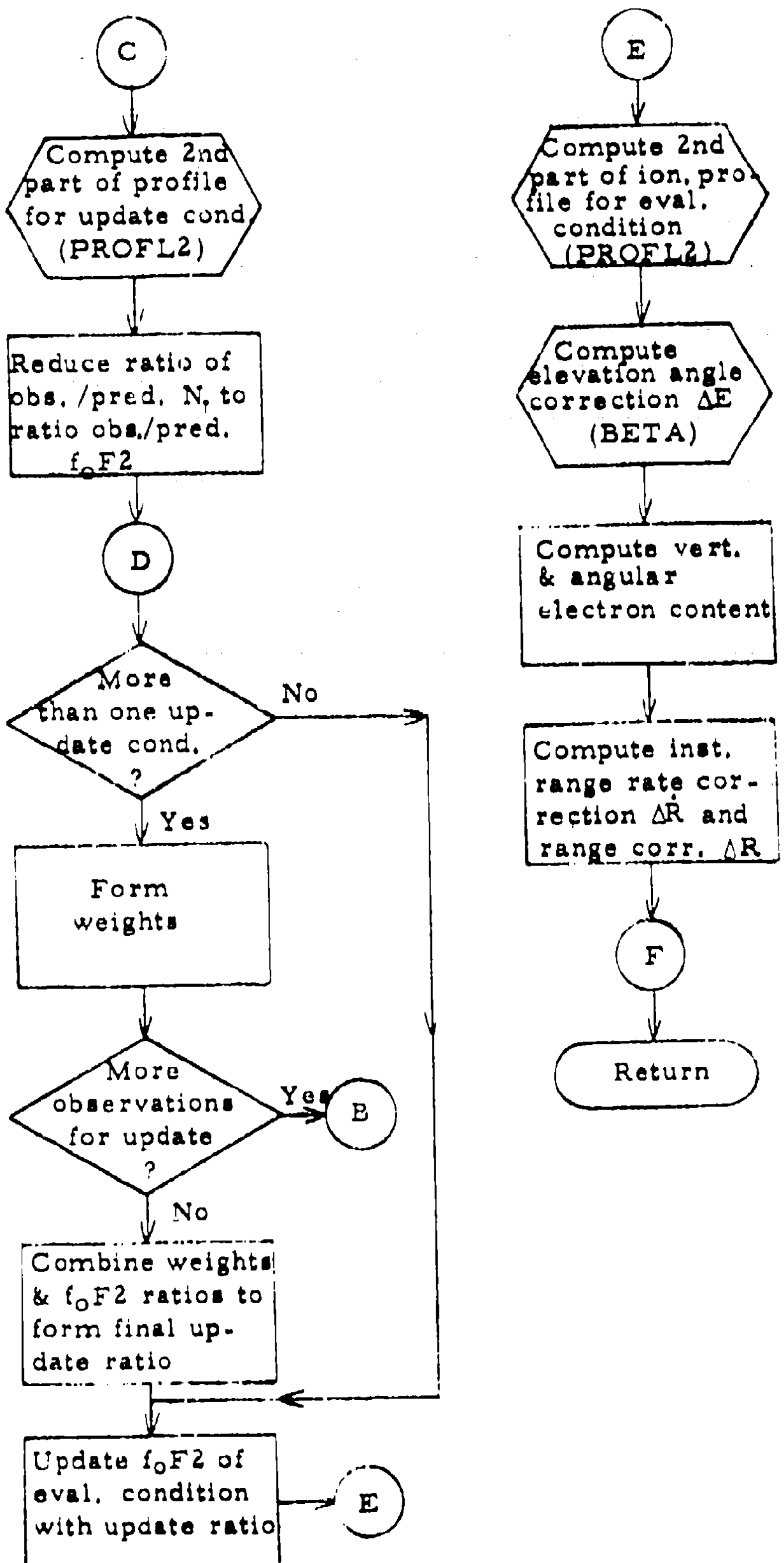
The range rate correction formula in this routine applies only to instantaneous range rate measurements, since it is assumed that the only

variation in electron content over the time of the observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant. If the range rate corrections are desired for observations obtained by range differencing over a finite time interval during which the ionosphere can undergo significant changes, a range correction differencing technique should be used over the same time interval. This type of correction can optionally be requested, it requires additional satellite and time information and is handled directly in PROGRAM ION, CPC No. 1.

If the ionospheric coefficients are not found on the tape for the evaluation date, an error condition has occurred, a message is printed out, and control is transferred to PROGRAM ION to proceed with the next data case.

CPC No. 2 Flowchart, SUBROUTINE REFRAC




C
Compute 2nd part of profile for update cond (PROFL2)
Reduce ratio of obs./pred. N_T to ratio obs./pred. f_oF2
D
More than one update cond. ?
No
Yes
Form weights
More observations for update ?
Yes
B
No
Combine weights & f_oF2 ratios to form final update ratio
Update f_oF2 of eval. condition with update ratio
E
E
Compute 2nd part of ion. profile for eval. condition (PROFL2)
Compute elevation angle correction ΔE (BETA)
Compute vert. & angular electron content
Compute inst. range rate correction $\Delta\dot{R}$ and range corr. ΔR
F
Return

3.2.1 Computer Program Component 3

CPC No.3, SUBROUTINE PLOTNH, is written in FORTRAN code. It is called from the main PROGRAM ION and lists and plots the electron density versus height profile.

3.2.1.1 CPC No. 3 Description

PLOTNH plots a graph of electron density N versus height h at 25 km height increments from 25 km to 1000 km and it prints a list of electron densities for corresponding height values from 25 km to 2000 km at 25 km increments

The electron density is modeled differently in five height layers (see Figure 2 in Section 6.1). k_1, k_2, k_3 denote the decay constants for the lower, middle and upper section of the exponential topside profile, and y_t, y_s are the values of half thickness for the topside parabolic layer and for the bottomside bi-parabolic layer respectively. The height limits for each layer are first determined and the value of electron density at the start point of the various layers N_s, N_0, N_1, N_2. The height increments measured from the start point of the various layers are denoted as variables b_1, b_2, a_1, a_2, a_3. The electron density equations are:

$$N = N_s \left(1 - \frac{b_2^2}{y_s^2}\right)^2 \qquad \text{for} \qquad h_s - y_s \le h < h_s$$

$$N = N_s \left(1 - \frac{b_1^2}{y_t^2}\right) \qquad \text{for} \qquad h_s \le h < h_0 = h_s + d$$

$$N = N_0\, e^{-k_1 a_1} \qquad \text{for} \qquad h_0 \le h < h_1 = h_0 + (1012\text{km} - h_0)/3$$

$$N = N_1\, e^{-k_2 a_2} \qquad \text{for} \qquad h_1 \le h < h_2 = h_1 + (1012\text{ km} - h_0)/3$$

$$N = N_2\, e^{-k_3 a_3} \qquad \text{for} \qquad h_2 \le h \le 2000\text{ km}$$

where h_m is the height at the maximum electron density, d is the distance above h_m at which the lower exponential layer starts, and the electron densities at the start points of the various layers,

$$N_m = 1.24 \times 10^{10} \, f_oF2^2$$

$$N_0 = N_m \left(1 - \frac{d^2}{y_t^2}\right)$$

$$N_1 = N_0 \, e^{-k_1 (h_1 - h_0)}$$

$$N_2 = N_1 \, e^{-k_2 (h_2 - h_1)}$$

3.2.1.2 CPC No. 3 Flowchart

The flowchart as shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 3 Interfaces

a) Library subprograms required: EXP, LOG10, SQRT

b) Other subprograms called: none

c) Calling program: SUBROUTINE REFRAC

d) Calling sequence: CALL PLOTNH (F0F2, HM, YM, YT, XK)

Variables in calling sequence:

Name	Dimension	I/O	Description
F0F2	1	I	Critical frequency (MHz)
HM	1	I	Height at the critical frequency (meters)
YM	1	I	Half thickness of the bottom bi-parabolic layer (meters)
YT	1	I	Half thickness of the topside parabolic layer (meters)
XK	3	I	Decay constants for lower, middle, and upper section of the topside exponential layer (1/meter)

e) Common blocks: none

f) File requirements: line printer

3.2.1.4 CPC No. 3 Data Organization

Variables defined in data statement:

Name	Dimension	Description
IBLANK	1	Hollorith "blank" symbol used for plotting
MARK	1	Hollorith " * " symbol used for plotting

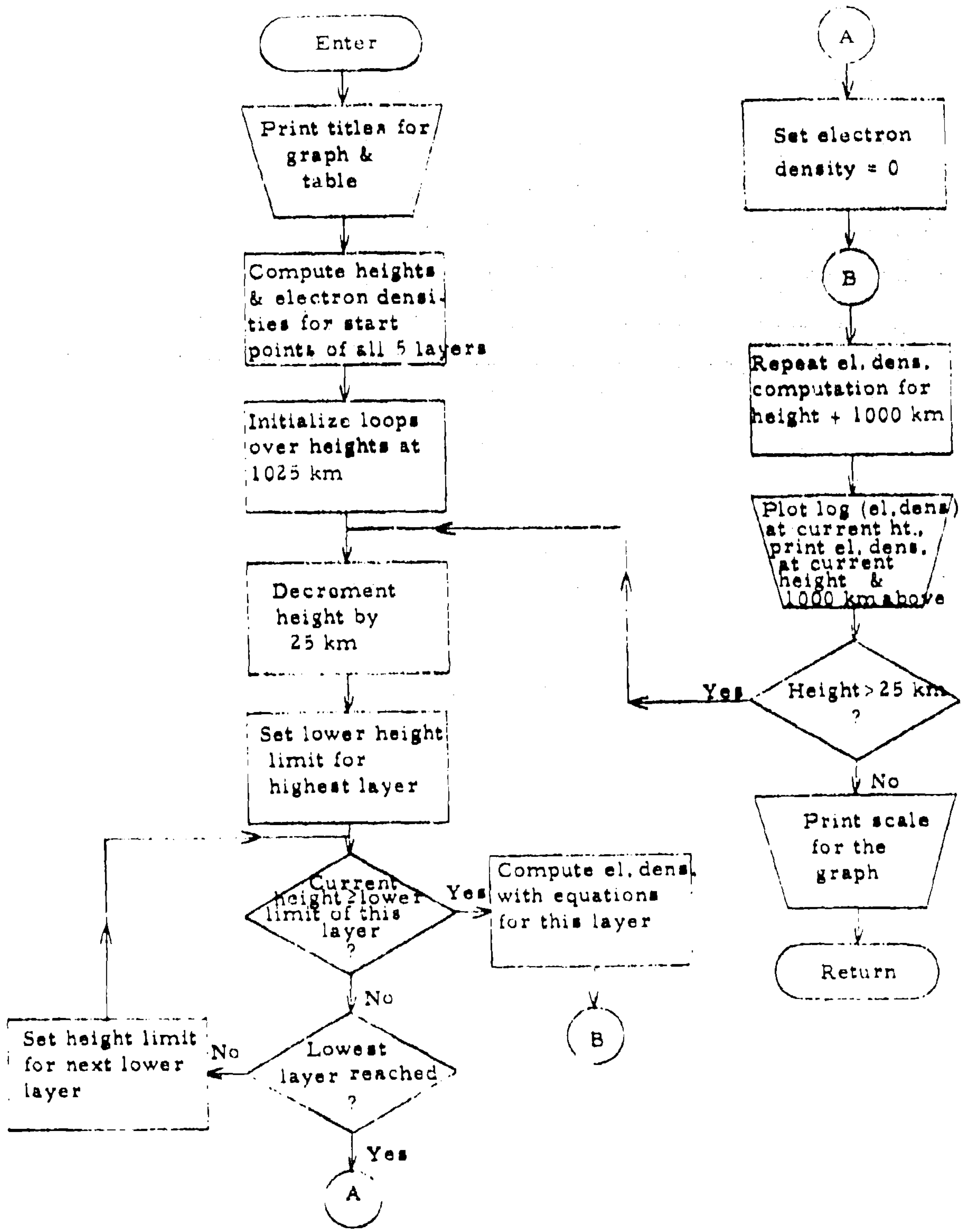
Other constants listed in data statement:

Q0=0, Q1=1, Q3=3, Q124E=1.24×10^{10}, Q1012E=1012000, Q1025E=1025000, Q25E=25000, Q10=10, Q27=27, Q2025E=2025000.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 3 Limitations

If electron density values are computed smaller than 10^{10} or larger than 5×10^{12} (electrons/meter^3), they exceed the limits of the graph and automatically are not plotted. Since these cases do not normally involve error conditions, a message is not required and the values are printed as computed in the electron density versus height list.


Enter
Print titles for graph & table
Compute heights & electron densities for start points of all 5 layers
Initialize loops over heights at 1025 km
Decrement height by 25 km
Set lower height limit for highest layer
Current height ≥ lower limit of this layer ?
Yes
Compute el. dens. with equations for this layer
B
No
Lowest layer reached ?
No
Set height limit for next lower layer
Yes
A
A
Set electron density = 0
B
Repeat el. dens. computation for height + 1000 km
Plot log (el. dens) at current ht., print el. dens. at current height & 1000 km above
Height > 25 km ?
Yes
No
Print scale for the graph
Return

3.2.1 Computer Program Component 4

CPC No. 4, SUBROUTINE PROFL1, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the ionospheric profile parameters critical frequency f_0F2 and the corresponding height h_s at the location where the wave passes through the ionosphere.

3.2.1.1 CPC No. 4 Description

PROFL1 computes the ionospheric characteristics f_0F2 and M(3000)F2 following the analysis of Jones, Graham and Leftin (Reference 5). First the trigonometric functions of the multiples of the Greenwich hour angle t, $-180° \leq t \leq 180°$, t=0 at Greenwich noon, are computed via SUBROUTINE SICOJT for use in DKSICO. The time dependent coefficients are computed via SUBROUTINE DKSICO based on the coefficient sets $U_{i,k}$ prepared in REFRAC. Utilizing the f_0F2 and M(3000)F2 coefficient sets (in arrays U and UM) the time dependent coefficients respectively for the f_0F2 and M(3000)F2 evaluation are prepared.

Defined by the latitude ϕ and longitude λ at which the ray from station to satellite passes through the ionosphere is the ionospheric point. It is calculated as a function of the station latitude ϕ_s, longitude λ_s, and the elevation angle E and azimuth angle A to the satellite;

$$\phi = \arcsin\left(\sin\phi_s \cos\alpha + \cos\phi_s \sin\alpha \cos A\right)$$

$$\lambda = \lambda_s + \arcsin\left(\frac{\sin A \sin\alpha}{\cos\phi}\right),$$

where α is the earth central angle between the station and the ionospheric point,

$$\alpha = \frac{\pi}{2} - E - \arcsin\left(\frac{R_e \cos E}{R_e + h_s}\right),$$

R_e is the mean earth radius, and h_s is the height of the ionosphere at the maximum electron density above the surface of the earth. Since h_s is to

be determined later on in this subroutine, a first estimate of h_s is required and assumed as h_s=300 km. After computing the actual h_s prediction, the new value is compared with the estimate and if it deviates by more than 1 km, all computations starting with the determination of the ionospheric point are repeated using the new h_s.

The position dependent functions required for the f_oF2 and M(3000)F2 computations are all evaluated at the ionospheric point which can differ by up to 21° from the station position. First the earth's magnetic field components X-north, Y-east and Z-vertical up are computed at the ionospheric point via SUBROUTINE MAGFIN, and they form in turn the modified magnetic dip x as a function of the magnetic dip I;

$$x = \arcsin \frac{I}{\sqrt{I^2 + \cos\phi}} \quad , \quad I = \arctan \frac{-Z}{\sqrt{X^2+Y^2}} \quad .$$

Based on the following coordinates, ionospheric latitude, longitude and modified magnetic dip, SUBROUTINE GK evaluates the geographic coordinate functions for the f_OF2 computation. Extracted from these functions is the subset which forms the geographic coordinate functions needed for the M(3000)F2 computation.

SUBROUTINE DKGK multiplies and sums the proper sets of time dependent coefficients and position dependent functions and forms M(3000)F2. With the Appleton-Beynon equations (Reference 1), a second order polynomial in M(3000)F2, the height of the maximum electron density is obtained in meters;

$$h_s = \left\{1346.92 - 526.40 \times M(3000)F2 + 59.825 \, [M(3000)F2]^2 \right\} \times 10^3$$

h_s is compared with its estimate and if the difference is greater than 1 km, the computations above starting with the ionospheric point determination are iterated on using the new value for h_s.

Using the proper time dependent coefficients and position dependent functions, SUBROUTINE DKGK computes the 10 day mean of the critical frequency which then is adjusted for day to day changes in the ionosphere and for additional magnetic latitude variations, following the model description in Section 6.1. The magnetic latitude of the ionospheric point is determined as,

$$\phi_a = \arc\sin\ [\sin\phi\ \sin\phi_p + \cos\phi\ \cos\phi_p\ \cos(\lambda - \lambda_p)]\ ,$$

where ϕ_p, λ_p are the latitude and longitude of the magnetic north pole and interpolating the model constants (array CENT) to ϕ_a results in c_2. The daily variation from the mean value is dependent on ΔF, the difference between the daily value and the 12-month running average of the solar flux and on the model constant c_1 (variable PER). The f_oF2 computed by DKGK is multiplied by the adjustment factor $(c_1\,\Delta F + c_2)$ to yield the final predicted f_oF2.

The units in the above equations are kept in meters, radians and MHz.

3.2.1.2 CPC No. 4 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 4 Interfaces

a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT

b) Other subprograms called: SUBROUTINES SICOJT, DKSICO, GK, MAGFIN, DKGK

c) Calling program: SUBROUTINE REFRAC

d) Calling sequence: CALL PROFL1(FLAT, FLON, ELEV, AZ, TIME, DFLUX, U, UM, OLAT, OLON, F0F2, HM, HLAT)

Variables in calling sequence:

Name	Dimension	I/O	Description
FLAT	1	I	Station latitude (radians)
FLON	1	I	Station longitude (radians)
ELEV	1	I	Elevation angle to satellite (radians)
AZ	1	I	Azimuth angle to satellite (radians)
TIME	1	I	Universal time (radians)
DFLUX	1	I	Difference between the daily value and the 12-month running average of the solar flux
U	13 x 76	I	Array containing coefficients used for the f_oF2 computation
UM	9 x 49	I	Array containing coefficients used for the M(3000)F2 computation
OLAT	1	O	Latitude of the ionospheric point (radians)
OLON	1	O	Longitude of the ionospheric point (radians)
F0F2	1	O	Critical frequency f_oF2 (MHz)
HM	1	O	Height at the maximum electron density h_m (meters)
HLAT	1	O	Magnetic latitude of the ionospheric point (radians)

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 4 Data Organization

Variables defined in data statements:

Name	Dimension	Description
K	10	Interger indices and index arrays used for the computation of f_oF2 and M(3000)F2 in SUBROUTINES DKSICO, GK and DKGK
KN	10	
KM10	1	
NFF	1	
NMF	1	
R	1	Mean earth radius (meters)
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole

Name	Dimension	Description
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
H1	1	Coefficients used in the formula expressing h_s as a second order polynomial of M(3000)F2
H2	1	
H3	1	
PER	1	Model constants used for adjusting f_oF2 for daily variation, dependent on the daily value and the 12-month running average of solar flux and magnetic latitude
CENT	3	

Other constants listed in data statements:

Q1=1, Q1000=1000, Q1P999=1.999999, Q3T6=3×10^6; D180=180°,

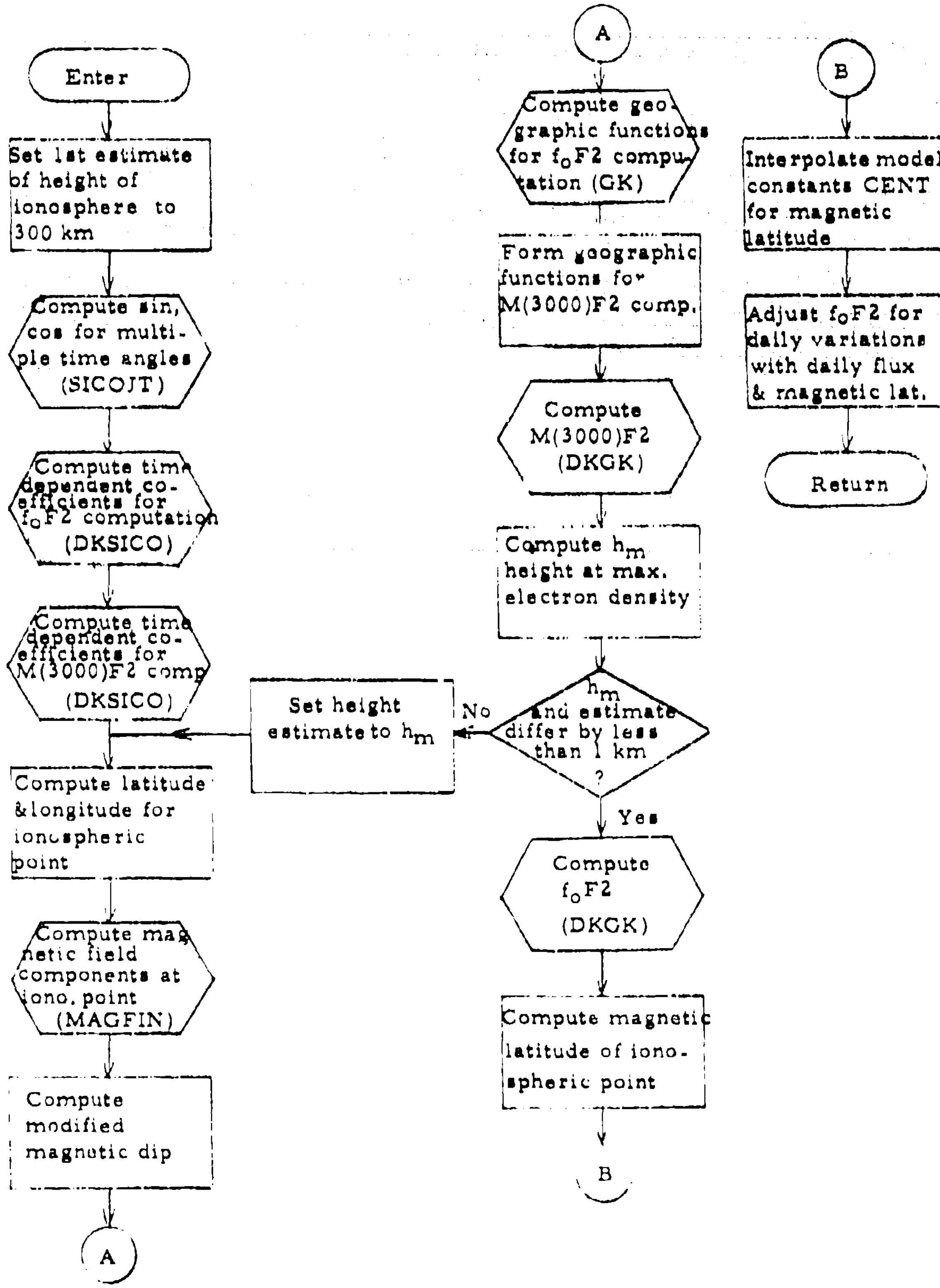
DG(1)=59°, DG(2)=28°, DG(3)=-33° converted to radians.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 4 Limitations

There are no program restrictions connected with this subroutine, and the limitations to the accuracy of the results obtained from the formulas are discussed in Section 6.2.

CPC No. - Flowchart, SUBROUTINE PROFL1



3.2.1 Computer Program Component 5

CPC No. 5, SUBROUTINE PROFL2, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the following ionospheric profile parameters: the values of half thickness y_m, y_t for the bottomside bi-parabola and the topside parabola respectively, the decay values k_1, k_2, k_3 for the topside exponential layers, the ratio N_T/N_m of the total content to the maximum electron density, and the multiplier m for use in the range rate computation.

3.2.1.1 CPC No. 5 Description

PROFL2 evaluates the ionospheric profile based on the model constants presented in graphic form in Section 6.1. The local time is computed from the universal time t and the longitude λ of the ionospheric point,

$$t_{loc} = t + \lambda \ .$$

The half thickness y_m of the bottomside bi-parabola varies with critical frequency f_oF2 and local time. Values of the half thickness are tabulated in array YMTAB at 1 MHz increments for $f_oF2=2, 3, \ldots 10$ MHz and at 2 hour intervals for $t_{loc}=0, 2, \ldots 22$ hours. To obtain y_m for the given conditions, the tables are interpolated in two dimensions between the fixed values; local time interpolation is carried continuously across the 0/24 hour mark, and the boundary values are assumed whenever f_oF2 is outside the limits 2 and 10 MHz.

For seasonal adjustments computation of the parameter $\Delta\chi$ (variable DSZA) is required. $\Delta\chi$ is the deviation of the daily value χ from the yearly average $\overline{\chi}$ of the noontime solar zenith angle. First the solar declination δ is evaluated for the given day,

$$\delta = \delta_{max} \sin\left[\frac{2\pi}{365}\ (\mathrm{JDAY}-80)\right],$$

$\delta_{max}=23.4444°$ is the maximum solar declination, JDAY is the day of the year. For stations in the northern hemisphere and outside the tropics,

with latitudes $\geq$ 23.4444°, $\Delta\chi=\delta$; for stations in the southern hemisphere and outside the tropics, $\Delta\chi=-\delta$. In the tropics the yearly average of the noontime solar zenith angle is computed as,

$$\bar{\chi} = \frac{2}{\pi}\left(\sqrt{\delta_{max}^2-\phi^2} + \phi \arcsin \frac{\phi}{\delta_{max}}\right),$$

ϕ being the latitude of the ionospheric point. The daily noontime solar zenith angle is $\chi=|\phi-\delta|$, and the difference $\Delta\delta=\bar{\chi}-\chi$.

The half thickness of the bottomside parabola y_m is multiplied by a seasonal adjustment factor that varies with $\Delta\chi$, local time and magnetic latitude ϕ_m. Adjustment factors are tabulated in array YRAT at 8° increments for $\Delta\chi$=24, 16, 8, 0, -8, -16, -24 degrees, at 6 hour intervals for t_{loc}=5.5, 11.5, 17.5, 24.5 hours where the absolute value of the magnetic latitude is greater or equal 15°, and at 12 hour intervals t_{loc}=3, 15 hours where $|\phi_m|\leq 5°$. The seasonal adjustment factor for the given conditions is obtained by three dimensional interpolation; the local time interpolation is carried continuously across the 0/24 hour mark and the magnetic latitude interpolation is only performed between 5 and 15 degrees.

The decay constants k_1, k_2, k_3 for the lower, middle and upper layer of the exponential topside are related to the daily solar flux F through the first order polynomial,

$$k_i = S_i \times F + C_i \quad , \; i = 1, 2, 3.$$

The slopes S_i, stored in array SLOP, and the intercepts C_i in array CEPT of this straight line relationship vary with magnetic latitude ϕ_m and with f_oF2. For each of the three topside layers, S_i and C_i are tabulated at 30° intervals for $|\phi_m|$ = 15, 45, 75 degrees, and at 3 MHz increments for f_oF2=2, 5, 8, 11 MHz. To obtain the decay constants for the given conditions, the tables for S_i and C_i are interpolated in two dimension between the fixed values, and whenever f_oF2 is outside the limits 2 and 11 MHz or $|\phi_m|$ is outside 15 and 75 degrees, the boundary values are used.

Seasonal effects are imposed on the topside by multiplying the decay constants by season adjustment factors that vary with the deviation $\Delta\chi$ in the solar zenith angle and with local time. The adjustment factors are tabulated in array RATK for each of the three topside layers at 8° increments for $\Delta\chi$=24, 16, 8, 0, -8, -16, -24 degrees, and at 6 hour intervals for t_{loc}=2, 8, 14, 20 hours. They are interpolated for each k_i, i=1, 2, 3 in two dimensions to the given conditions; the local time interpolation is carried continuously across the 0/24 hour mark.

The half thickness of the topside parabola, extending from the point of maximum electron density to the lower exponential layer, is dependent on y_m and f_oF2 through the relationship,

$$y_t = \begin{cases} y_m & , \text{ for } f_oF2 \leq 10.5 \\ y_m \;[1 + 0.133333\,(f_oF2 - 10.5)] & , \text{ for } f_oF2 > 10.5 \end{cases} \quad .$$

The distance d above the height at maximum electron density h_m where the slopes of the parabola and the lower exponential layer are the same is,

$$d = \frac{1}{k_1}\left(\sqrt{1 + k_1^2\, y_t^2} - 1\right) \quad .$$

The total vertical electron content N_T is obtained by integrating the electron density profile from zero to the height of the satellite h_s. The program computes the ratio of total electron content to the maximum electron density N_T/N_m (variable XNTNM) by one of the following six equations depending on the upper integration limit. At the same time, the multiplier m (variable RRM) required for the instantaneous range rate computation is evaluated and its formulation also varies depending on the height of the satellite. For a satellite below the bi-parabolic layer of the ionosphere:

$$N_T/N_m = 0 \quad ,$$

$$m = 0 \quad .$$

For a satellite in the bottomside bi-parabolic layer with half thickness y_m:

$$N_T = N_m \left\{ \frac{8}{15} y_m - (h_m - h_s) + \frac{2}{3} \frac{(h_m - h_s)^3}{y_m^2} - \frac{1}{5} \frac{(h_m - h_s)^5}{y_m^4} \right\} ,$$

$$m = \left[1 - \left(\frac{h_m - h_s}{y_m} \right)^2 \right]^2 .$$

For a satellite in the topside parabolic layer with half thickness y_t:

$$N_T = N_m \left\{ \frac{8}{15} y_m - (h_m - h_s) + \frac{1}{3} \frac{(h_m - h_s)^3}{y_t^2} \right\} ,$$

$$m = 1 - \left(\frac{h_m - h_s}{y_t} \right)^2 .$$

For a satellite in the lower exponential layer of the topside with decay constant k_1:

$$N_T = N_m \left(1 - \frac{d^2}{y_t^2} \right) \left\{ \frac{1}{k_1} \left(1 - e^{-k_1 (h_s - h_0)} \right) \right\} + N_s ,$$

and the height of the bottom of the lower exponential layer is $h_0 = h_m + d$, and

$$N_s = N_m \left\{ \frac{8}{15} y_m - (h_m - h_0) + \frac{1}{3} \frac{(h_m - h_0)^3}{y_t^2} \right\} ,$$

$$m = \left(1 - \frac{d^2}{y_t^2} \right) e^{-k_1 (h_s - h_0)}$$

For a satellite in the middle exponential layer of the topside with decay constant k_2:

$$N_T = N_m \left(1 - \frac{d^2}{y_t^2} \right) \left\{ \frac{1}{k_1} + e^{-k_1 (h_1 - h_0)} \left[- \frac{1}{k_1} + \frac{1}{k_2} \left(1 - e^{-k_2 (h_s - h_1)} \right) \right] \right\} + N_s ,$$

and the height of the bottom of the middle exponential layer is:

$$h_1 = h_0 + \frac{1}{3}(1.012 \times 10^6 - h_0),$$

$$m = \left(1 - \frac{d^2}{y_t^2}\right) e^{-k_1 (h_1 - h_0)} e^{-k_2 (h_s - h_1)} .$$

For a satellite in the upper exponential layer of the topside with decay constant k_3:

$$N_T = N_s \left(1 - \frac{d^2}{y_t^2}\right)\left\{\frac{1}{k_1} + e^{-k_1 (h_1 - h_0)}\left[-\frac{1}{k_1} + \frac{1}{k_2} + e^{-k_2 (h_2 - h_1)}\left(-\frac{1}{k_2} + \frac{1}{k_3} - \frac{1}{k_3} e^{-k_3 (h_s - h_2)}\right)\right]\right\} + N_s ,$$

and the height of the bottom of the upper exponential layer is,

$$h_2 = h_0 + \frac{2}{3}(1.012 \times 10^6 - h_0).$$

$$m = \left(1 - \frac{d^2}{y_t^2}\right) e^{-k_1 (h_1 - h_0)} e^{-k_2 (h_2 - h_1)} e^{-k_3 (h_s - h_2)} .$$

3.2.1.2 CPC No. 5 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 5 Interfaces

a) Library subprogram required: ABS, AMOD, ATAN, EXP, SIN, SQRT

b) Other subprograms called: none

c) Calling program: SUBROUTINE REFRAC

d) Calling sequence: CALL PROFL2 (OLAT, OLON, HS, TIME, IDAY, MON, FLUX, F0F2, HM, HLAT, YM, YT, XK, RRM, XNTNM)

Variables in calling sequence:

Name	Dimension	I/O	Description
OLAT	1	I	Latitude of ionospheric point (radians)
OLON	1	I	Longitude of ionospheric point (radians)
HS	1	I	Height of satellite above earth's surface (meters)
TIME	1	I	Universal time (radians)
IDAY	1	I	Day (=1 through 31)
MON	1	I	Month (=1 through 12)
FLUX	1	I	Daily solar flux value
F0F2	1	I	Critical frequency (MHz)
HM	1	I	Height at maximum electron density (meters)
HLAT	1	I	Magnetic latitude of ionospheric point (radians)
YM	1	O	Half thickness of the bottom bi-parabolic layer (meters)
YT	1	O	Half thickness of the topside parabolic layer (meters)
XK	3	O	Decay constants for lower, middle and upper section of the topside exponential layer (1/meter)
RRM	1	O	Multiplier of the $\dot{h}$ term in the range rate formula (dimensionless)
XNTNM	1	O	Ratio of total vertical electron content to the electron density (meters)

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 5 Data Organization

Variables defined in data statements:

Name	Dimension	Description
SO1	1	Maximum solar declination (radians)
SO2	1	Multiplier to convert 365 days to 2π radians (radians/day)

Name	Dimension	Description
RN4	1	Average frequency to which topside sounders measured the ionospheric profiles is RN4 $\times f_oF2$
H1012	1	Average height to which topside exponential layer was modeled (meters)
CEPT SLOP	$4\times3\times3$ $4\times3\times3$	Model constants used for computing the decay constants for the lower, middle and upper section of the topside exponential layer, dependent on daily solar flux, critical frequency and magnetic latitude
RATK	$4\times4\times3$	Model constants used for adjusting the computed decay constants for the lower, middle and upper exponential topsides for seasonal effects, dependent on the difference between the yearly average and the daily value of the noontime solar zenith angle and on local time
YMTAB	12×9	Model constants used for computing the half thickness of the bottomside bi-parabola, dependent on local time and critical frequency
YRAT	7×6	Model constants used for adjusting the computed half thickness of the bottomside bi-parabola for seasonal effects, dependent on the difference between the yearly average and the daily value of the noontime solar zenith angle, on local time and magnetic latitude

Other constants listed in data statements for convenience:

Q0=0, Q1=1, Q2=2, Q3=3, Q4=4, Q5=5, Q6=6, Q8=8, Q24=24, Q37=37,

Q1000=1000, QP05=.05, QP1333=.133333, QP95=.95, Q2P5=2.5,

Q10P5=10.5, Q8O15=.533333333;

D5=5°, D7P5=7.5°, D8=8°, D10=10°, D16=16°, D30=30°, D135=135°,

D180=180°, PIH=90°, PI2=360°, DEG(1)=75°, DEG(2)=45°, DEG(3)=15°

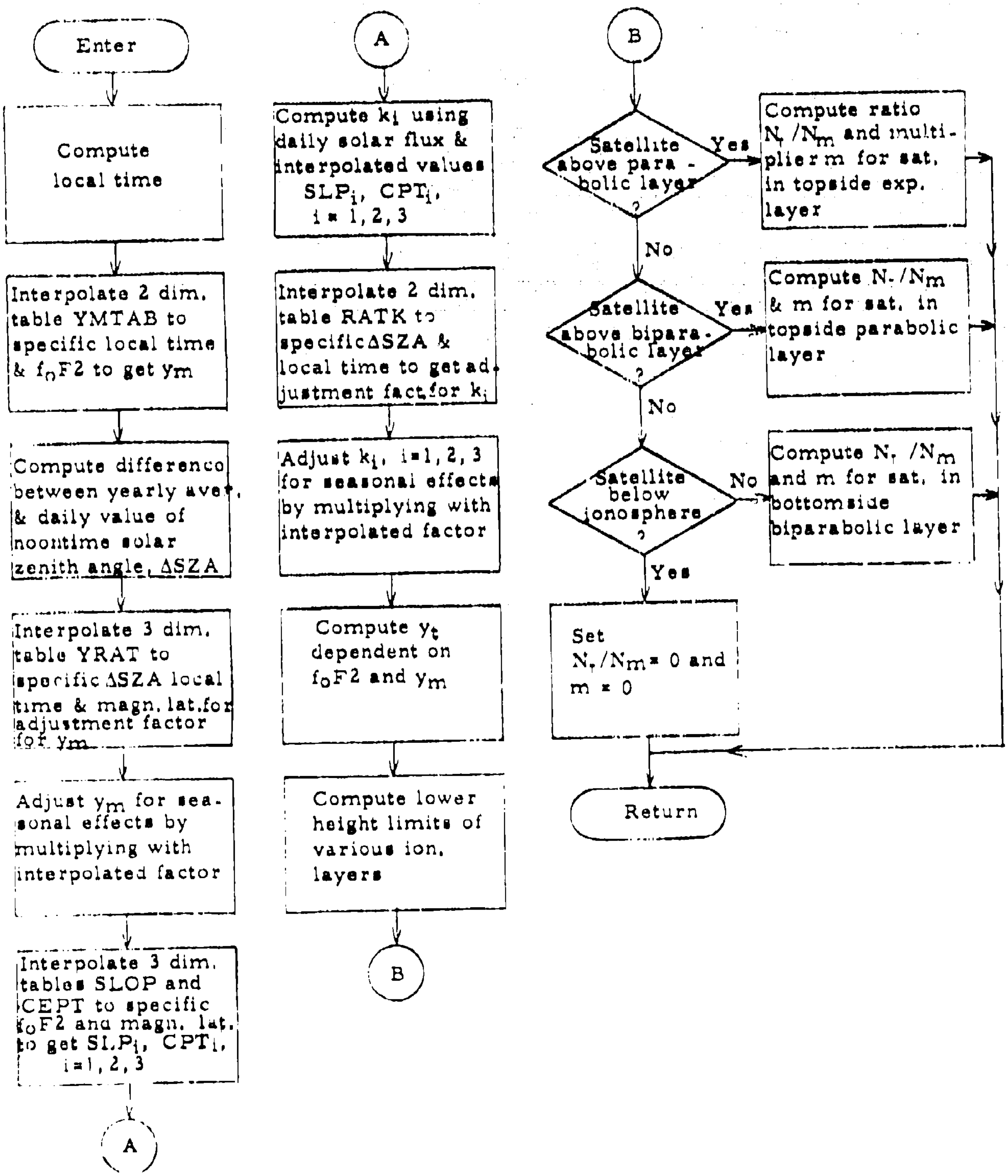
converted to radians.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 5 Limitations

There are no programming restrictions connected with this subroutine, and the limitations to the accuracy of the results obtained from the formulas are discussed in Section 6.2.

CPC No. 5 Flowchart, SUBROUTINE PROFL2



3.2.1 Computer Program Component 6

CPC No. 6, SUBROUTINE BETA, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the ionospheric refraction correction for the elevation angle.

3.2.1.1 CPC No. 6 Description

BETA computes the angular refraction correction to the elevation angle. Using the results of Maliphant's work (Reference 8), the deviation angle α is expressed as the angle between the true ray path above the ionosphere and the apparent ray path.

$$\alpha = \frac{1}{2}\left(\frac{f_0F2}{f}\right)^2 \xi \; \frac{\tan\varphi_0 \; \sec^2\varphi_0}{r_0} \; \frac{N_T}{N_m} \quad ,$$

where f is the transmission frequency, f_0F2 the critical frequency, N_T the total electron content, N_m the maximum electron density;

$$r_0 = R_e + h_m + 0.5333 \; y_m \quad ,$$

and R_e is the earth radius, h_m the height of the maximum electron density, and y_m the half thickness of the bottom layer of the ionosphere;

$$\varphi_0 = \text{arc sin}\left(\frac{R_e}{r_0} \; \cos E\right) \quad , \text{ E being the elevation angle,}$$

and ξ is a function of the squared deviation factor $(\sec\varphi_m \times f_0F2/f)^2$ and is interpolated from tabulated values ξ^{-1}; $\varphi_m = \text{arc sin}\left(\frac{R_e}{R_e+h_L} \; \cos E\right)$.

After determinating α the following two auxiliary equations are evaluated,

$$X_1 = \left[(R_e+h_s)^2 - R_e^2\cos^2 E\right]^{\frac{1}{2}} + R_e \; \cos E \tan\frac{\alpha}{2}$$

$$X_2 = R_e \; \sin E - R_e \; \cos E \tan\frac{\alpha}{2} \quad .$$

The elevation angle correction ΔE is then given by,

$$\Delta E = \text{arc cos} \frac{X_1 \cos\alpha - X_2}{(X_1^2 + X_2^2 - 2X_1X_2 \cos\alpha)^{\frac{1}{2}}} ,$$

3.2.1.2 CPC No. 6 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 6 Interfaces

a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT

b) Other subprograms called: none

c) Calling program: SUBROUTINE REFRAC

d) Calling sequence: CALL BETA (FRAT, XNTNM, HS, HM, YM, SE, CE, DELEV)

Variables in calling sequence:

Name	Dimension	I/O	Description
FRAT	1	I	Square ratio of critical frequency to the transmission frequency
XNTNM	1	I	Ratio of total electron content to the electron density (meter)
HS	1	I	Height of the satellite above the earth's surface (meters)
HM	1	I	Height of the maximum electron density (meters)
YM	1	I	Half thickness of the bottom layer of the ionosphere (meters)
SE	1	I	Sine function of the elevation angle
CE	1	I	Cosine of the elevation angle
DELEV	1	O	Ionospheric refraction correction to the elevation angle (radians)

e) Common blocks: none

f) File requirements: line printer

3.2.1.4 CPC No. 6 Data Organization

Variables defined in data statements:

Name	Dimensions	Description
XAX	5	Values of the squared deviation factor $(\sec \varphi_r \times f_oF2/f)^2$ for which the function ξ^{-1} is tabulated
YAX	5	Tabulation of the function ξ^{-1} as given in Reference 8
R	1	Mean earth radius (meters)

Other constants listed in data statements:

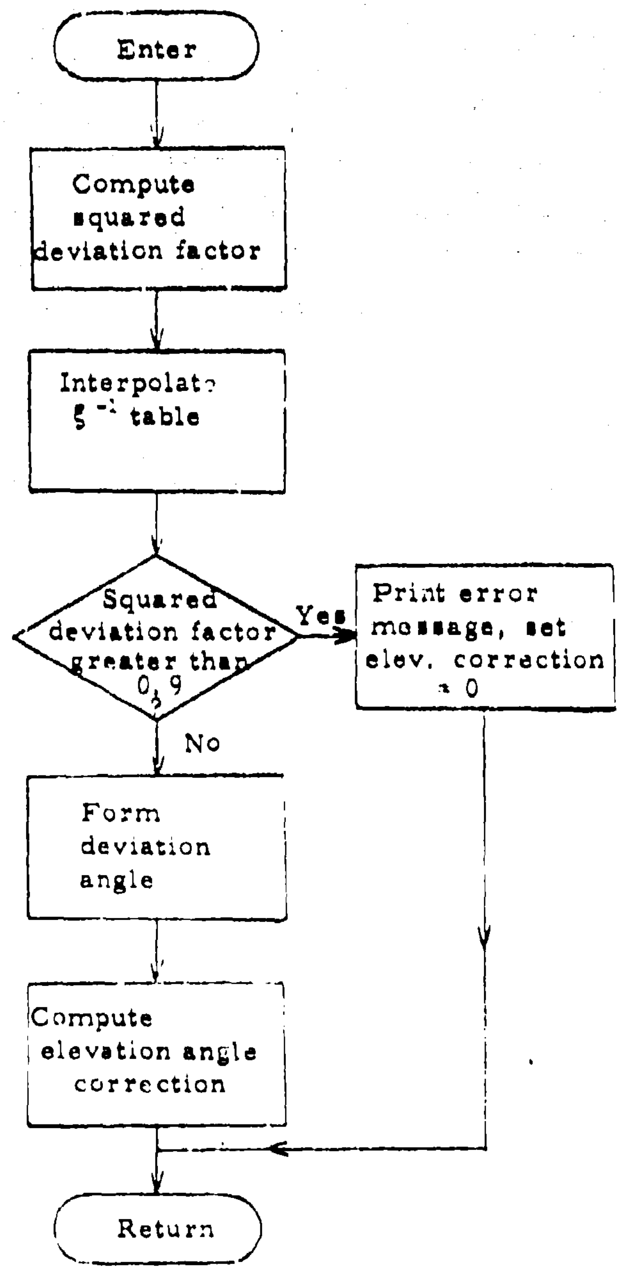
Q0=0, Q1=1, Q2=2, Q5333=.5333

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 6 Limitations

The equations for the deviation angle α which are coded into SUBROUTINE BETA are accurate everywhere except right about reflection conditions. Whenever the deviation factor $(\sec \varphi_s \times f_oF2/f)$ is less than 0.9, all equations are valid; this means the results are correct whenever the component of the wave frequency vertical to the ionosphere is slightly larger than the critical frequency $(1.1 \times f_oF2)$. But the more the deviation factor exceeds 0.9, the larger the errors might be in the computation for α and therefore ΔE. An error check, programmed into the routine, tests if the deviation factor is greater than 0.9 in which event a zero elevation angle correction is returned and an error message is printed.

CPC No. 6 Flowchart, SUBROUTINE BETA



3.2.1 Computer Program Component 7

CPC No. 7, SUBROUTINE SICOJT, is coded in FORTRAN code. It is called from SUBROUTINES PROFL1 and MAGFIN and performs auxiliary computations by expressing the multiple angle trigonometric functions.

3.2.1.1 CPC No. 7 Description

SICOJT computes the trigonometric functions for multiples of the angle. It forms sin(jT), cos(jT) for j=1,..., L by computing sinT, cosT for the single angle T, and by using for multiple angles the recursive equations:

$$\sin\left[(j+1)T\right] = \sin T\ \cos(jT) + \cos T\ \sin(jT)$$
$$\cos\left[(j+1)T\right] = \cos T\ \cos(jT) - \sin T\ \sin(jT).$$

3.2.1.2 CPC No. 7 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 7 Interfaces

a) Library subprograms required: COS, SIN

b) Other subprograms called: none

c) Calling programs: SUBROUTINES PROFL1 and MAGFIN

d) Calling sequence: CALL SICOJT (L, C, S, T)

Variables in calling sequence:

Name	Dimension	I/O	Description
L	1	I	The largest integer by which T is to be multiplied
C	L	O	Array containing values cos(jT), j=1,..., L
S	L	O	Array containing values sin(jT), j=1,..., L
T	1	I	The angle (radians)

e) Common blocks: none

f) File requirements: none

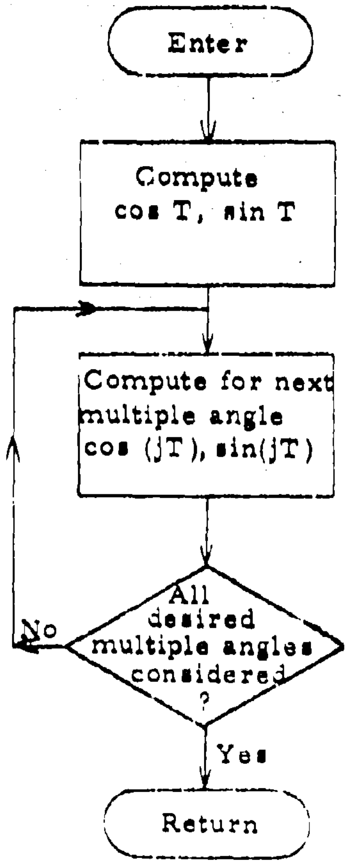
3.2.1.4 CPC No. 7 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 7 Limitations

None.

CPC No. 7 Flowchart, SUBROUTINE SICOJT



3.2.1 Computer Program Component 8

CPC No. 8, SUBROUTINE DKSICO, is written in FORTRAN code. It is called from SUBROUTINE PROFL1 and calculates the time dependent coefficients which are required for the computation of critical frequency and associated height.

3.2.1.1 CPC No. 8 Description

DKSICO forms the orthonormal coefficients D_k for a fixed time T represented by the Fourier series representation,

$$D_k(T) = U_{0,k} + \sum_{j=1}^{H} \left[U_{2j,k} \cos(jT) + U_{2j-1,k} \sin(jT) \right] \quad , k=1,\ldots,K.$$

These coefficients are to be used for the computation of the ionospheric characteristics in DKGK. The number of harmonics retained in the series is H, higher harmonics are not considered since they are produced more by noise than by real physical variation. For the f_OF2 computation H=6 and for the M(3000)F2 computation H=4 are sufficient. The coefficients $U_{i,k}$ are either a monthly predicted coefficient set for M(3000)F2 or a ten day predicted coefficient set for f_OF2, which are both specific subsets derived from the generalized f_OF2 and M(3000)F2 coefficients in SUBROUTINE REFRAC. The D_k coefficients are computed for each term in a series with cutoff point K, K=75 for the series expressing f_OF2 and K=48 for the series representing M(3000)F2.

3.2.1.2 CPC No. 8 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 8 Interfaces

a) Library subprograms required: none

b) Other subprograms called: none

c) Calling program: SUBROUTINE PROFL1

d) Calling sequence: CALL DKSICO (MX, LH, D, SITIME, COTIME, DK)

Variables in calling sequence:

Name	Dimension	I/O	Description
MX	1	I	Cutoff index = cutoff point of series +1
LH	1	I	Number of harmonics retained in Fourier series representation of D_k
D	(LH*2+1)*MX	I	Predicted coefficient array $U_{i,k}$ for f_oF2 or for M(3000)F2
SITIME	LH	I	Array of values sin(jT)
COTIME	LH	I	Array of values cos(jT)
DK	MX	O	Array of coefficients D_k at fixed time T, k=0, . . . , K

e) Common blocks: none

f) File requirements: none

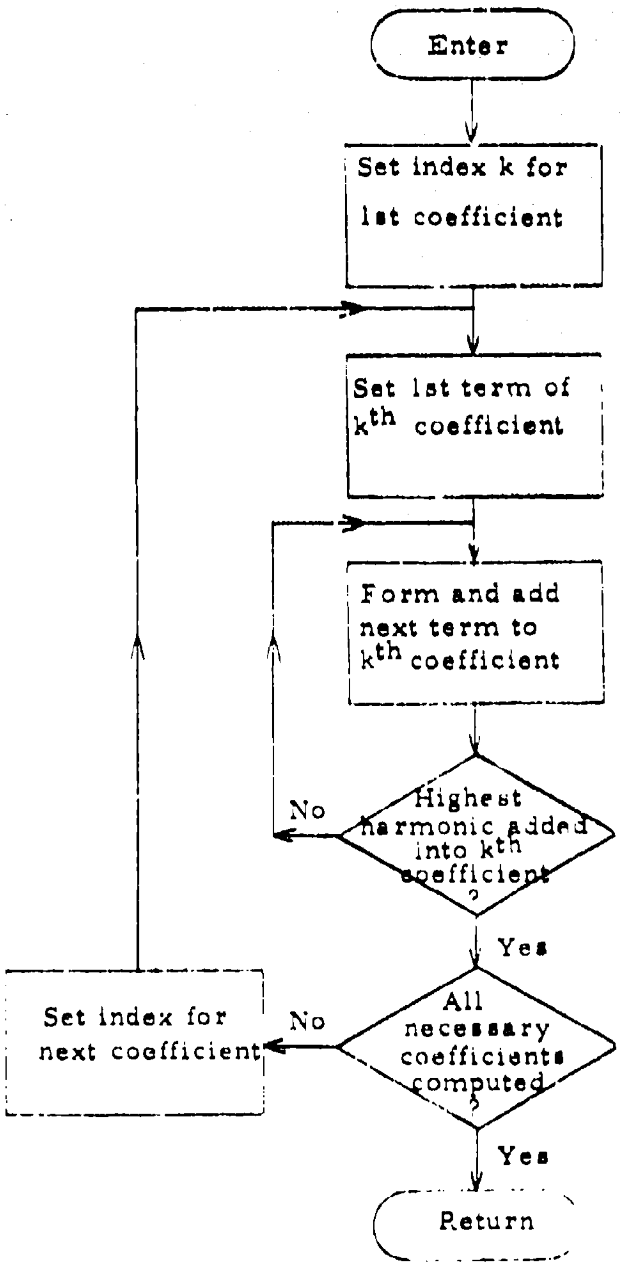
3.2.1.4 CPC No. 8 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 8 Limitations

None.

CPC No. 8 Flowchart, SUBROUTINE DKSICO



3.2.1 Computer Program Component 9

CPC No. 9, SUBROUTINE MAGFIN, is written in FORTRAN code. It is called from SUBROUTINE PROFL1 and evaluates the magnetic field components at the point where the wave penetrates the ionosphere. The field components are required for the computation of the critical frequency and the associated height.

3.2.1.1 CPC No. 9 Description

MAGFIN computes the earth's magnetic field components at a desired location following the spherical harmonic analysis of the magnetic field by Chapman and Bartels (Reference 3) and using the coefficients g_n^m, h_n^m given by Jensen and Cain (Reference 4) for Epoch 1960. The X-north, Y-east, and Z-vertical (up) components of the magnetic field are used for the computation of the modified magnetic dip in SUBROUTINE PROFL1.

Using the specified point (ϕ, λ, h_m'), the colatitude is introduced $\varphi=90°-\phi$, and the ratio $R=R_e/(R_e+h_m')$, where R_e is the radius of the earth and h_m'=300 km is the F2 layer height on which the coefficient analysis was based. The trigonometric functions $\sin(m\lambda)$, $\cos(m\lambda)$ for the multiple longitude angle λ are computed via SUBROUTINE SICOJT. The magnetic field components are defined in the following equations and are obtained by first expressing the multiple of the associated Legendre function and its derivative, then accumulating the terms of the inner sums and finally forming the outer sums.

$$X = \sum_{n=1}^{6} \left\{ R^{n+2} \sum_{m=0}^{n} \frac{d}{d\varphi} P_{n,m}(\cos\varphi) \left[g_n^m \cos(m\lambda) + h_n^m \sin(m\lambda) \right] \right\}$$

$$Y = \frac{1}{\sin\varphi} \sum_{n=1}^{6} \left\{ R^{n+2} \sum_{m=0}^{n} m\, P_{n,m}(\cos\varphi) \left[g_n^m \sin(m\lambda) - h_n^m \cos(m\lambda) \right] \right\}$$

$$Z = \sum_{n=1}^{6} \left\{ (n+1)\, R^{n+2} \sum_{m=0}^{n} P_{n,m}(\cos\varphi) \left[g_n^m \cos(m\lambda) + h_n^m \sin(m\lambda) \right] \right\}$$

The multiple of the associated Legendre function is given by,

$$P_{n,m}(\cos\theta) = \sin^m\theta \left[\cos^{n-m}\theta - \frac{(n-m)(n-m-1)}{2(2n-1)} \cos^{n-m-2}\theta + \frac{(n-m)(n-m-1)(n-m-2)(n-m-3)}{(2)(4)(2n-1)(2n-3)} \cos^{n-m-4}\theta - \cdots \right]$$

3.2.1.2 CPC No. 9 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 9 Interfaces

a) Library subprograms required: ABS, SIGN, SIN, SQRT

b) Other subprograms called: SUBROUTINE SICOJT

c) Calling program: SUBROUTINE PROFL1

d) Calling sequence: CALL MAGFIN (POS, UNE)

Variables in calling sequence:

Name	Dimension	I/O	Description
POS	3	I	Array containing latitude, longitude and height (radians and meters)
UNE	3	O	Array with Z (vertical up), X(north), and Y(east) components of magnetic field (gauss) at the location specified by POS

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 9 Data Organization

Variables defined in data statements:

Name	Dimension	Description
CT	7 x 7	Array containing coefficients for the computation of the associated Legendre function
G	7 x 7	Array of g_n^m coefficients given in Reference 4 for the earth magnetic field for Epoch 1960
H	7 x 7	Array of h_n^m coefficients given in Reference 4 for the earth magnetic field for Epoch 1960

Name	Dimension	Description
RE	1	Mean earth radius (meters)

Other constants listed in data statements;

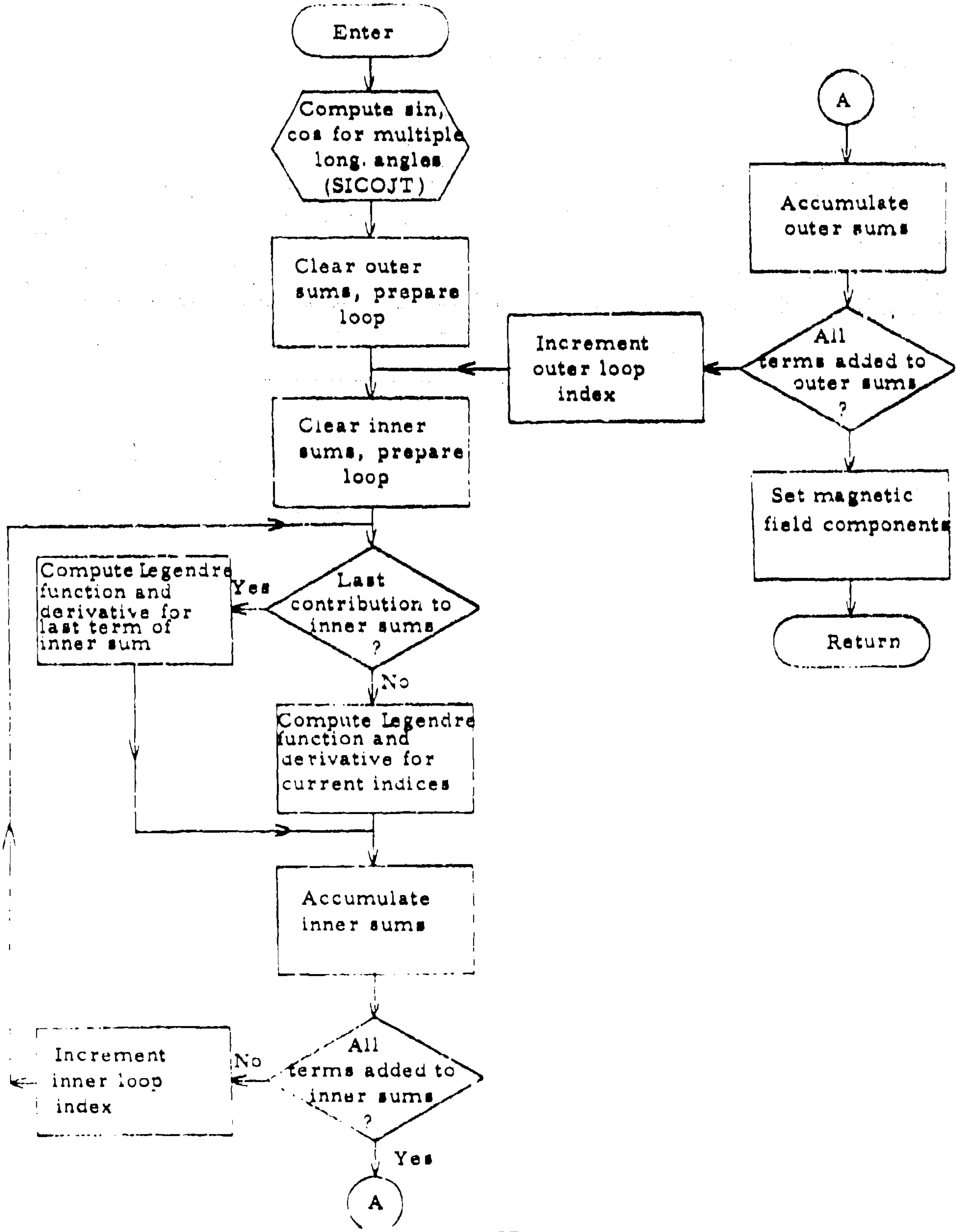
P(1, 1)=1, DP(1, 1)=0, SP(1)=0, CP(1)=1, Q0=0; R899=89.9° converted to radians

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 9 Limitations

None.

CPC No. 9 Flowchart, SUBROUTINE MAGFIN



3.2.1 Computer Program Component 10

CPC No. 10, SUBROUTINE GK, is written in FORTRAN code. It is called from SUBROUTINE PROFL1 and calculates the geographic coordinate functions which are required for the computation of critical frequency and associated height.

3.2.1.1 CPC No. 10 Description

GK computes the geographic coordinate functions G_k as a function of latitude ϕ, longitude λ, and modified magnetic dip $x = x(\phi, \lambda)$, which itself is dependent on the geographic position. These coordinate functions are to be used for the computation of the ionospheric characteristic f_oF2 in subroutine DKGK. The functions G_k represent the main latitudinal variation and the first order through 8th order longitudinal variation terms. The main latitudinal variation is expressed as,

$$G_k = \sin^k x \qquad \text{for } k = 0, 1, \ldots, 11,$$

and the jth order longitude terms are computed as,

$$G_k = \left.\begin{cases} (\sin x)^{(k-m_j)/2} \cos^j\phi \cos(j\lambda) & \text{, for } k \text{ even} \\ (\sin x)^{(k-m_j-1)/2} \cos^j\phi \sin(j\lambda) & \text{, for } k \text{ odd} \end{cases}\right\} k = m_j, (m_j+1), \ldots, (m_{j+1}-1).$$

The longitude orders are $j = 1, 2, \ldots, 8$ while $k = 12, 13, \ldots, 75$, and the indexing is defined by: $m_1 = 12$, $m_2 = 36$, $m_3 = 54$, $m_4 = 64$, $m_5 = 68$, $m_6 = 70$, $m_7 = 72$, $m_8 = 74$.

3.2.1.2 CPC No. 10 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 10 Interfaces

a) Library subprograms required: COS, SIN

b) Other subprograms called: none

c) Calling program: SUBROUTINE PROFL1

d) Calling sequence: CALL GK (K,C,G)

Variables in calling sequence:

Name	Dimension	I/O	Description
K	10	I	Integer index array containing $(m_j - 1)$
C	3	I	Array containing modified magnetic dip, geographic latitude and longitude (radians)
G	76	O	Array with geographic functions G_k, $k=0,\ldots 75$

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 10 Data Organization

Constants defined in data statements:

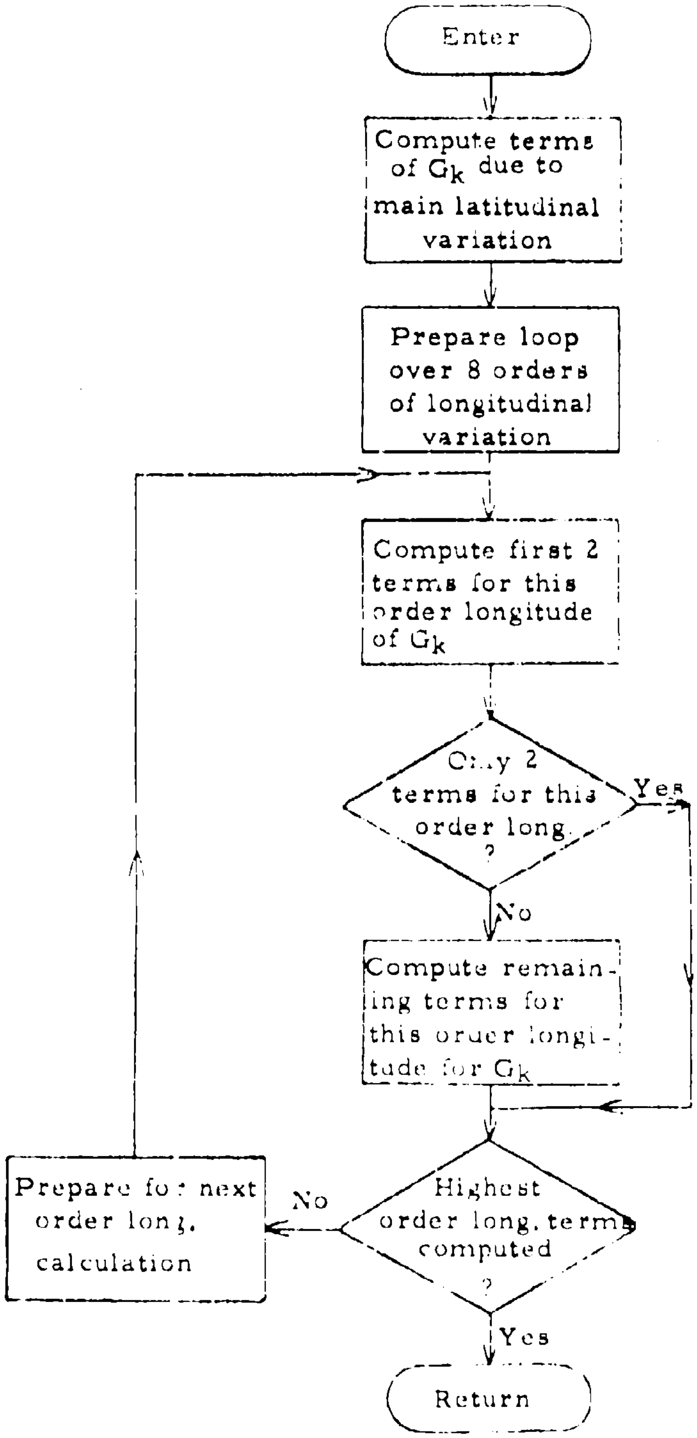
Q1=1, N=8= Highest order of longitude included in G_k computation.

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 10 Limitations

None.

CPC No. 10 Flowchart, SUBROUTINE GK



3.2.1 Computer Program Component 11

CPC No. 11, SUBROUTINE DKGK, is written in FORTRAN code. It is called from SUBROUTINE PROFL1 and computes the critical frequency or the associated height depending on the input.

3.2.1.1 CPC No. 11 Description

DKGK computes the ionospheric characteristic Ω, by forming a series of products of time dependent coefficients D_k and position dependent geographic functions G_k,

$$\Omega(\phi, \lambda, T) = \sum_{k=0}^{K} D_k(T) \quad G_k(\phi, \lambda).$$

The coefficients D_k are precomputed for a fixed time T, and the geographic functions G_k are for a fixed latitude ϕ and longitude λ. K is the cutoff point for the approximate series representation of Ω. For the determination of the ionospheric characteristic $\Omega = f_oF2$ the cutoff point K=75 is used and for the calculation of Ω=M(3000)F2 the cutoff point is K=48. The inputs D_k and G_k are specifically set for either the f_oF2 or the M(3000)F2 computation.

3.2.1.2 CPC No. 11 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 11 Interfaces

a) Library subprograms required: none

b) Other subprograms called: none

c) Calling program: SUBROUTINE PROFL1

d) Calling sequence: CALL DKGK (MX, G, DKSTAR, OMEGA)

Variables in calling sequence:

Name	Dimension	I/O	Description
MX	1	I	Cutoff index=cutoff point K of series +1
G	MX	I	Array of geographic functions G_k, k=0, . . . , K
DKSTAR	MX	I	Array of coefficients D_k, k=0, . . . , K
OMEGA	1	O	Ionospheric characteristic f_0F2(MHz) or M(3000)F2 (dimensionless)

e) Common blocks: none

f) File requirements: none

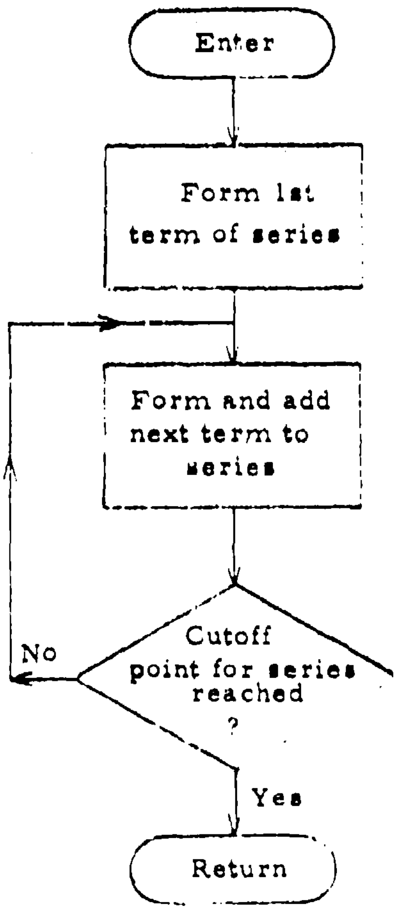
3.2.1.4 CPC No. 11 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 11 Limitations

None.

CPC No. 11 Flowchart, SUBROUTINE DKGK



3.2.1 Computer Program Component 12

CPC No. 12, main PROGRAM TABGEN, is written in FORTRAN code. For any specified date and station preprocessor TABGEN computes values of critical frequency and corresponding height for 14 time intervals at each of 25 locations around the station covering the visible ionosphere. The resulting f_oF2-h_m tables are written onto file for use in the ionospheric reduction program ION1.

3.2.1.1 CPC No. 12 Description

TABGEN reads the date, station, and solar flux information from card for which f_cF2-h_m tables are to be generated. It lists the input data for reference in the print out and converts the units of the angles to radians. The general coefficients are read from tape if not already available and the specific coefficient sets required for the f_oF2 and M(3000)F2 computation are prepared as well as the solar data. The applicable procedures are already described in the first four paragraphs of Section 3.2.1.1, CPC No. 2.

A pattern of 25 points is generated around the station as shown in Figure 1; the point distribution covers the visible ionosphere in fairly even density. The earth central angle α between station and ionospheric point varies in 7° increments, while the azimuth A is 0° for $\alpha=0°$, and rotates in 90° steps for $\alpha=7°$, in 45° steps for $\alpha=14°$, and in 30° steps for $\alpha=21°$ out of the northern position. For each ionospheric point the geographic latitude ϕ and longitude λ and the magnetic latitude ϕ_m are reduced from the station position ϕ_s, λ_s, the position of the magnetic north pole ϕ_p, λ_p and α and A;

$$\phi = \arcsin(\sin\phi_s \cos\alpha + \cos\phi_s \sin\alpha \cos A)$$

$$\lambda = \lambda_s + \arcsin\left(\frac{\sin A \sin\alpha}{\cos\phi}\right)$$

$$\phi_m = \arcsin\left[\sin\phi \sin\phi_p + \cos\phi \cos\phi_p \cos(\lambda-\lambda_p)\right].$$

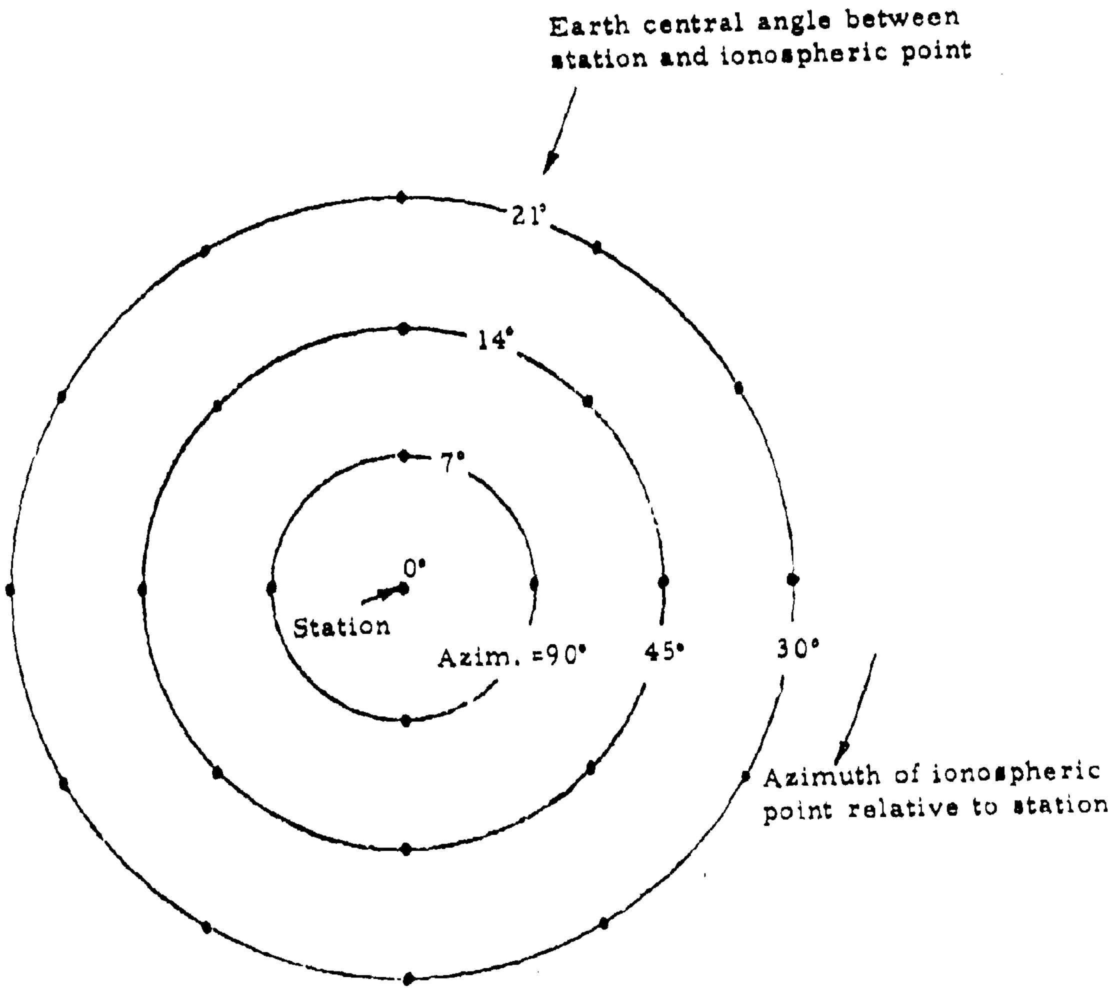


Figure 1. 25 Point Pattern of Ionospheric Points around Station

The position dependent functions required for the f_oF2 and M(3000)F2 computation are evaluated using SUBROUTINE MAGFIN and GK as described in the third paragraph of Section 3.2.1.1, CPC No. 4.

The diurnal variation at each of the 25 points is produced by evaluating the critical frequency and corresponding height at 14 different time intervals at 0, 2, 4, 5, 6, 7, 8, 10, 12, 14, 16, 18, 20, 22 hours of local time. The time pattern is densified around sunrise to properly represent the rapid change in the ionosphere during that time. f_oF2 and M(3000)F2 are computed by preparing the time dependent coefficients via SUBROUTINES SICOJT and DKSICO and combining the time dependent coefficients and position dependent functions by calling SUBROUTINE DKGK. The height of the maximum electron density h_s is computed with the Appleton-Beynon equation (Reference 1) in units of km;

$$h_s = 1346.92 - 526.40 \times M(3000)F2 + 59.825 \left[M(3000)F2\right]^2 .$$

The critical frequency is adjusted for day to day variations as a function of ΔF, the difference between the daily value and the 12-month running average of the solar flux. Using the model constants c_1 (variable PER) and c_2 obtained by interpolating the constant table (array CENT) to the magnetic latitude of the ionospheric point, f_oF2 is multiplied by the adjustment factor $(c_1 \Delta F + c_2)$.

For each point and time f_oF2 and h_s are coded into one 8 digit integer, the first four digits defining h_s in units of $\frac{1}{10}$ km the last 4 digits specifying f_oF2 in units $\frac{1}{100}$ MHz. The f_oF2-h_s table is accumulated for all 14 time intervals and all 25 points, and is written to tape or disc file along with the date, station, and solar flux information. The process can be repeated for any number of date and station conditions desired, by specifying additional input data and repeating the steps outlined in this section.

3.2.1.2 CPC No. 12 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 12 Interfaces

a) Library subprograms required: AMOD, ATAN, COS, SIN, SQRT

b) Other subprograms called: SUBROUTINES MAGFIN, GK, SICOJT, DKSICO, DKGK

c) Calling programs: none

d) Calling sequence: PROGRAM TABGEN

e) Common blocks: none

f) File requirements: general coefficient input tape, output disc or tape file with f_oF2-h_s tables, card reader, line printer

The formats of the general coefficient input tape of the f_oF2-h_s table output file and the requirements for the input data card file are specified under 3.3.1.

3.2.1.4 CPC No. 12 Data Organization

Variables defined in data statements:

Name	Dimension	Description
JAZ	4	Index array specifying number of azimuth angle divisions for each earth central angle used in 25 point pattern
ITP	1	Unit assignment of general ionospheric coefficient tape
JTP	1	Unit assignment of file with f_oF2-h_s tables
MONDY	1	Initialization constants for last and first (month × 100+day) for which coefficients are in core
MOND	1	
LYRMO	1	Initialization constant for (year × 100+month)
K	10	Integer indices and index arrays used for the computation of f_oF2 and M(3000)F2 in SUBROUTINES DKSICO, GK, and DKGK
KN	10	
KM10	1	
NFF	1	
NMF	1	

Name	Dimension	Description
PER	1	Model constants used for adjusting f_oF2 for daily variation, dependent on the daily value of the 12-month running average of solar flux and magnetic latitude
CENT	3	
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
H1	1	Coefficients used in the formula expressing h_m as a second order polynomial of M(3000)F2
H2	1	
H3	1	

Other constants listed in data statements:

Q1=1, Q10=10, Q100=100, Q130=130, Q3T5=3×10^5, QP1=.1, QP5=.5;

DR=1°, PI2=360°, D7=7°, DHR1=1^h, DHR2=2^h, D180=180°,

DG(1)=59°, DG(2)=28°, DG(3)=-33° converted to radians.

3.2.1.5 CPC No. 12 Limitations

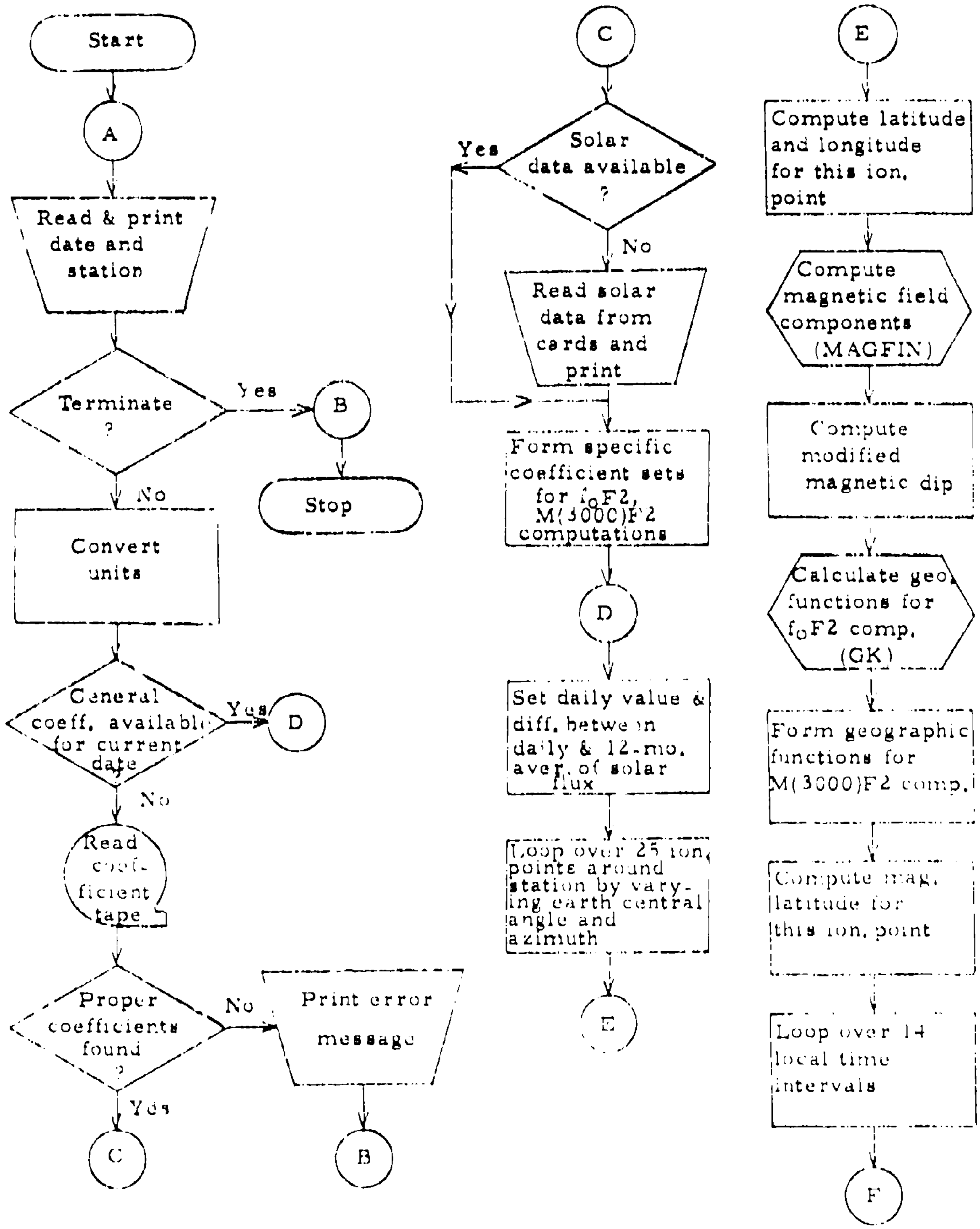
The daily value of solar flux transferred through the data file to the ionospheric reduction program for computation of the decay constants for the topside exponential profile is truncated a a maximum value of 130. This is the boundary that was imposed by the data base during model development and extension of solar flux beyond 130 could result in invalid profiles.

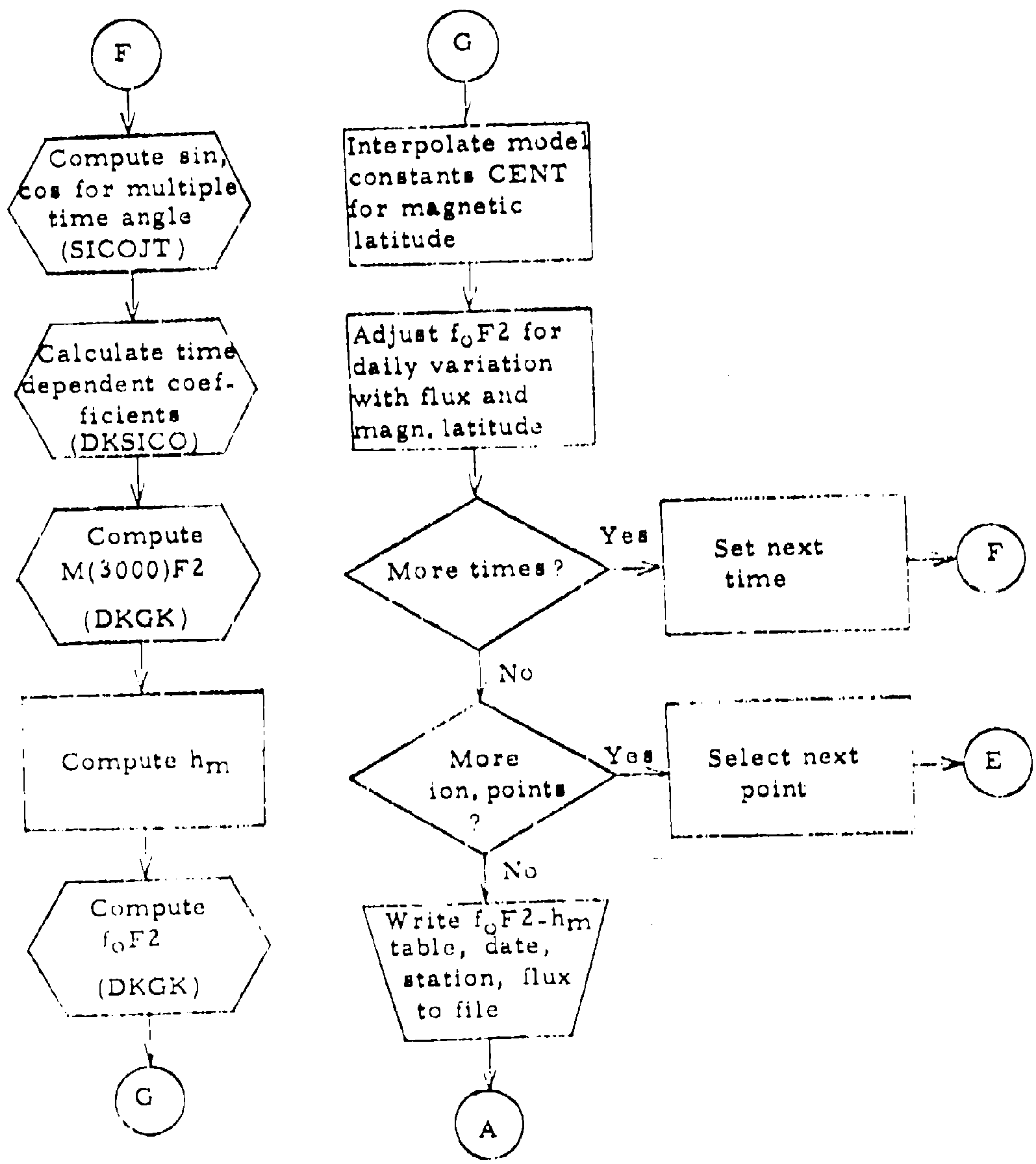
Approximations are introduced through bypassing the iteration on the height estimate of the ionosphere. In this case the latitude and longitude of the ionospheric points are not effected, only the height itself at which the magnetic field components are evaluated. Error estimates for these approximations are not yet available.

If the ionospheric coefficients are not found on the tape for the specified date, an error condition has occurred, a message is printed out, and the program is terminated.

The solar input data cards are checked for consistency of the date and if disagreement is found, a message is printed and the program is terminated.

CPC No. 12 Flowchart, PROGRAM TABGEN




F
Compute sin, cos for multiple time angle (SICOJT)
Calculate time dependent coef-ficients (DKSICO)
Compute M(3000)F2 (DKGK)
Compute h_m
Compute f_oF2 (DKGK)
G
G
Interpolate model constants CENT for magnetic latitude
Adjust f_oF2 for daily variation with flux and magn. latitude
More times?
Yes
Set next time
F
No
More ion. points ?
Yes
Select next point
E
No
Write f_oF2-h_m table, date, station, flux to file
A

3.2.1 Computer Program Component 13

CPC No. 13, main PROGRAM ION1, is written in FORTRAN code. It handles the card input and the printing of the results for the entire program. ION1 transfers the input conditions through common/EVAL1/, and by calling SUBROUTINE REFRC1 receives the computed profile parameters and refraction corrections through common/CORR1/.

3.2.1.1 CPC No. 13 Description

ION1 reads the station, satellite, and time information for the condition to be evaluated from cards. The input data is converted to the internal units of meters for distances and radians for angles and times. The variables specifying the evaluation condition are transferred through common/EVAL1/ to SUBROUTINE REFRC1. Through REFRC1 and other routines called by REFRC1, ionospheric profile parameters, vertical and angular electron content, refraction corrections to elevation angle, range, and instantaneous range rate are computed. They are returned to ION1 through common/CORR1/ and are printed.

Any number of evaluation conditions can be processed by supplying additional input data and repeating the program steps outlined above. For more details about the input and output data refer to the file descriptions under 3.3.1.

3.2.1.2 CPC No. 13 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 13 Interface

a) Library subprograms required: none

b) Other subprograms called: SUBROUTINE REFRC1

c) Calling programs: none

d) Calling sequence: PROGRAM ION1

e) Common blocks: EVAL1, CORR1

Variables in Common:

See description for EVAL1, CORR1 under SUBROUTINE REFRC1, CPC No. 14

f) File requirements: card reader, line printer

The requirements for the input data card file are specified under 3.3.1.

3.2.1.4 CPC No. 13 Data Organization

Constants defined in data statement:

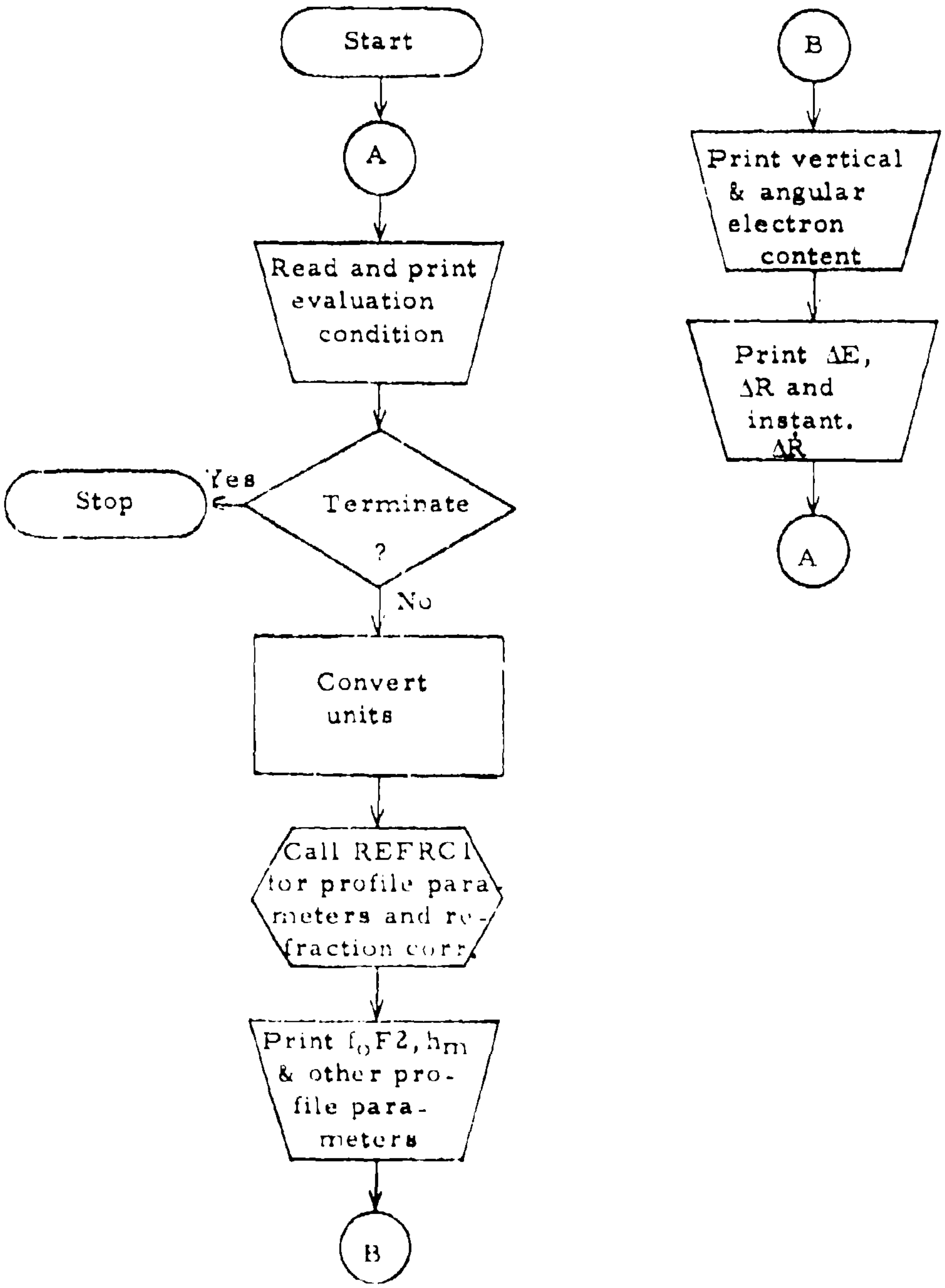
Q0=0, Q1000=1000, Q3600=3600; DR=1°, HR=1^h converted to radians. Important variables are described under 3.2.1.3 e) of SUBROUTINE REFRC1, CPC No. 14.

3.2.1.5 CPC No. 13 Limitations

Error tests on the sequence, units, and formats of the input data are not performed. However, mistakes in the set up of the card deck are revealed in the printout of the input data that is listed along with the results.

ION1 is a program for special applications and limited use compared to the general purpose PROGRAM ION. Not included in ION1 are the additional features of ION of plotting the ionospheric profile, of updating the predictions with actual ionospheric observations, and of computing range rate corrections for range differencing. For the purpose of saving space only four digits are carried for f_0F2 and h_s in the f_0F2-h_s tables which eliminates the option of differencing range corrections where the 5th and 6th digit of f_0F2 are significant to the result. Because of approximations in TABGEN and REFRC1, ION1 also yields less accurate results than ION.

CPC No. 13 Flowchart, PROGRAM ION1



3.2.1 Computer Program Component 14

CPC No. 14, SUBROUTINE REFRC1, is written in FORTRAN code and is called from main PROGRAM ION1. REFRC1 extracts the f_0F2-h_s tables from tape or disc file and interpolates the values in the tables to the specified position and time. The remaining profile parameters are obtained via SUBROUTINE PROFL2, the ionospheric refraction corrections to range ΔR, to instantaneous range rate $\Delta\dot{R}$ are computed and SUBROUTINE BETA provides the elevation angle correction ΔE.

3.2.1.1 CPC No. 14 Description

REFRC1 retrieves the f_0F2-h_s tables from the tape or disc file that was prepared by the preprocessor TABGEN, if the tables for the given evaluation condition are not already available. Data for up to four station and date combinations can be kept in core simultaneously which greatly reduces the IO requirements for data reductions where a few stations are observing intermittently. In addition, if new data is requested, it automatically replaces of the four tables the one having been in core for the longest time.

The earth central angle between station and ionospheric point, the geographic latitude and longitude, and the magnetic latitude of the ionospheric point are computed using the equations shown in Section 3.2.1.1, CPC No. 4. Local time t_{loc} is computed from the universal time t and the longitude λ,

$$t_{loc} = t + \lambda$$

Critical frequency and corresponding height are extracted from the f_0F2-h_s table containing data for 14 time intervals during the specified day at each of 25 locations covering the visible ionosphere around the given station. A linear interpolation process is used in three dimensions, in azimuth, earth central angle, and local time. First it is arranged for indexing purposes that azimuth lies between 0 and 360 degrees, central angle between 0 and 90 degrees, and local time between 0 and 24 hours. The indices

and increments for the interpolation are computed for all three variables. Continuous interpolation is insured between 22 and 0 hours of local time and between the highest value and 0 degrees of azimuth for each central angle. The limiting values at 21 degrees are used if due to some rare occasion or an error condition, the earth central angle should exceed 21 degrees; this value was arrived at for the extreme condition of an observer looking horizontally at a 453 km high ionosphere.

By calling SUBROUTINES PROFL2 and BETA the remaining profile parameters and the refraction correction to the elevation angle are evaluated respectively. Vertical and angular total electron content as well as the refraction corrections to range and instantaneous range rate, are computed following the description in the last five paragraphs of Section 3.2.1.1, CPC No. 2.

3.2.1.2 CPC No. 14 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 14 Interfaces

a) Library subprograms required: ABS, AMOD, ATAN, COS, FLOAT, SIN, SQRT

b) Other subprograms called: SUBROUTINES PROFL2, BETA

c) Calling program: PROGRAM ION1

d) Calling sequence: SUBROUTINE REFRC1

e) Common blocks: EVAL1, CORR1

Variables in common:

Common Name	Variable Name	Dimension	I/O	Description
EVAL1	FS	1	I	Transmission frequency (MHz)
EVAL1	FLAT	1	I	Latitude of station (radians)
EVAL1	FLON	1	I	Longitude of station (radians)

Common Name	Variable Name	Dimension	I/O	Description
EVAL1	ELEV	1	I	Elevation to satellite (radians)
EVAL1	AZ	1	I	Azimuth to satellite (radians)
EVAL1	HS	1	I	Height of satellite (m)
EVAL1	EDOT	1	I	Elevation rate (radians/sec)
EVAL1	HDOT	1	I	Altitude rate (m/sec)
EVAL1	TIME	1	I	Universal time (radians)
EVAL1	IYR	1	I	Year (last 2 digits)
EVAL1	MON	1	I	Month (=1 through 12)
EVAL1	IDAY	1	I	Day (=1 through 31)
EVAL1	JTP	1	I	Unit assignment of ionospheric file with f_0F2-h_s tables
CORR1	DRANG	1	O	Range correction (m)
CORR1	DRATE	1	O	Range rate correction (m/sec)
CORR1	DELEV	1	O	Elevation angle correction (radians)
CORR1	F0F2	1	O	Critical frequency (MHz)
CORR1	HM	1	O	Height at maximum electron density (meters)
CORR1	YM	1	O	Half thickness of the bottomside bi-parabolic layer (meters)
CORR1	YT	1	O	Half thickness of the topside parabolic layer (meters)
CORR1	XK	3	O	Decay constants of lower, middle, and upper section of the exponential topside layer (1/meter)
CORR1	TOIN	1	O	Total vertical electron content (e/m^2 column)
CORR1	TOTNA	1	O	Total angular electron content (e/m^2 column)

f) File requirements: ionospheric input tape or disc file with f_0F2-h_s tables. The format of the file containing the f_0F2-h_s tables is described under 3.3.1.

3.2.1.4 CPC No. 14 Data Organization

Variables defined in data statements:

Name	Dimension	Description
JAZ	4	Index arrays used in defining the 25 point pattern around the station
KAZ	4	
NO	1	Initialization constants for storage condition of $f_oF2\text{-}h_s$ tables
NR	1	
R	1	Mean earth radius (meters)
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
RM	1	Estimate for radial distance of ionosphere from earth center (meters)
TOL	1	Tolerance allowed in identifying station latitude and longitude (radians)

Other constants listed in data statements:

Q0=0, Q1=1, Q2=2, Q7=7, Q100=100, Q3P5=3.5, Q4P5=4.5, QNM=1.24×10^{10}, RN3=.49972; PI2=360°, DR=1°, HR=1^h converted to radians.

Other important variables are described under 3.2.1.3 e).

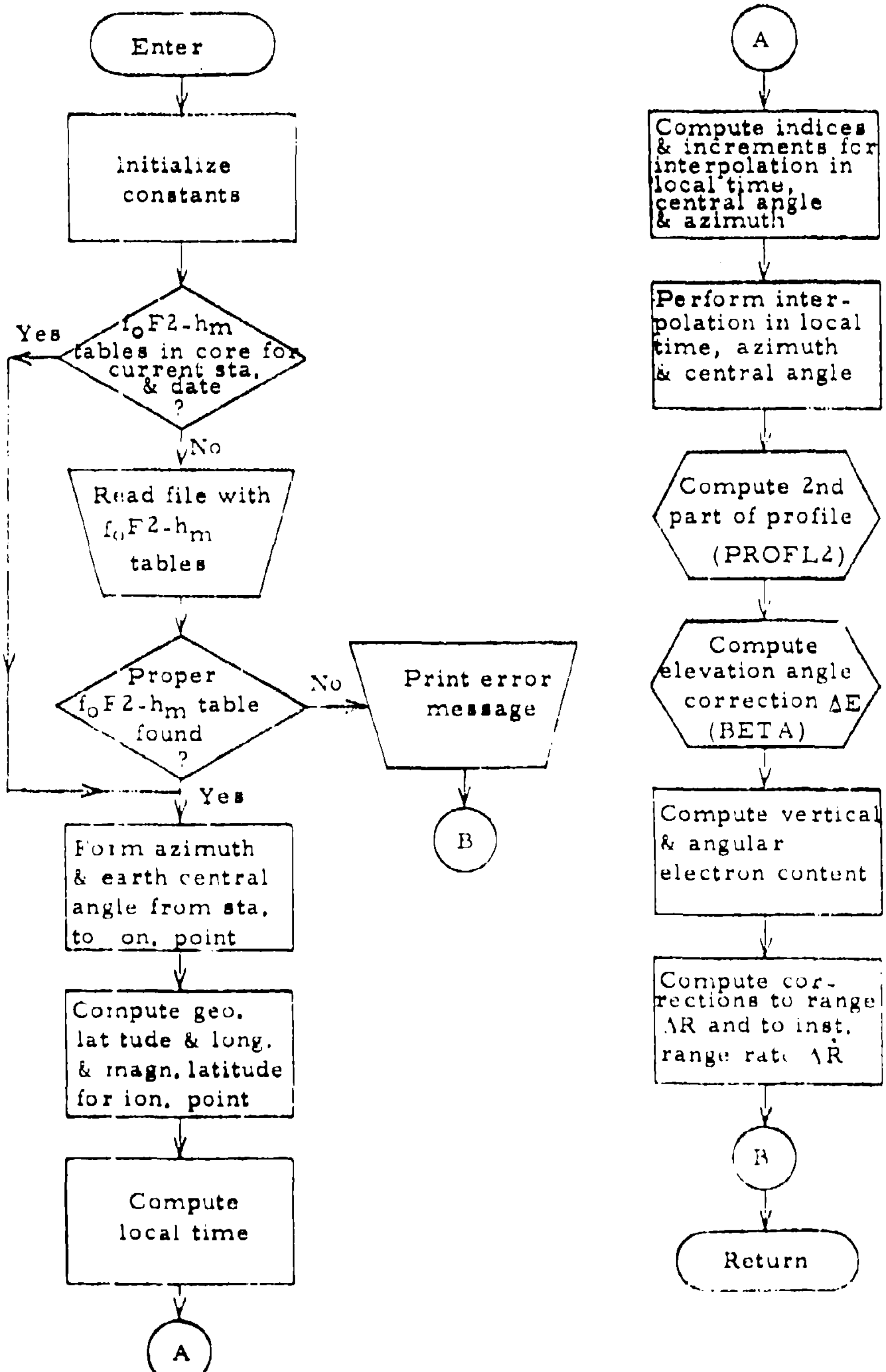
3.2.1.5 CPC No. 14 Limitations

Approximations are introduced into the computation of the critical frequency and the height of the maximum electron density by two facts; through the linear interpolation in space and time of the precomputed $f_oF2\text{-}h_s$ tables, and through bypassing the iteration on the height estimate of the ionosphere. Thus caution should be used and further tests of accuracy requirements might be desired when using this program version. An estimate of the expected errors is given in Section 6.2.

The range rate correction formula in this routine applies only to instantaneous range rate measurements since it is assumed that the only variation in electron content over the time of observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant. Range rate corrections to observations obtained by range differences over a finite time interval during which the ionosphere can undergo distinct changes, cannot be computed by this routine because the f_oF2-h_s tables do not carry enough significant digits. For this purpose PROGRAM ION should be used.

If the f_oF2-h_s table for the specified date and station is not found in the data file, an error message is printed out and control is transferred to PROGRAM ION1 to proceed with the next data case.

CPC No. 14 Flowchart, SUBROUTINE REFRC 1



3.3 Storage Allocation

The size requirements and storage allocations of the total programs and the individual components were extracted from computer runs of the programs on the CDC 6600 computer system. In the load maps that are shown on the following pages the starting addresses of the program and system functions in the detailed breakdown are listed in octal words.

The total core space requirements are:

37604 octal = 16260 decimal words for the Bent Ionospheric PROGRAM ION;
24232 octal = 10394 decimal words for the preprocessor PROGRAM TABGEN,
6524 octal = 3412 decimal words for the reduction PROGRAM ION1
of the alternate version of the ionospheric program.

Following are the size requirements for the individual components:

Component		Size in decimal words
COMMON	/EVAL/	20
COMMON	/UPDT/	57
COMMON	/CORR/	12
PROGRAM	ION	3841
SUBROUTINE	REFRAC	5426
SUBROUTINE	PLOTNH	366
SUBROUTINE	PROFL1	624
SUBROUTINE	PROFL2	1085
SUBROUTINE	BETA	180
SUBROUTINE	SICOJT	64
SUBROUTINE	DKSICO	72
SUBROUTINE	MAGFIN	520
SUBROUTINE	GK	147
SUBROUTINE	DKGK	39
COMMON	/EVAL1/	13
COMMON	/CORR1/	12
PROGRAM	TABGEN	10394
PROGRAM	ION1	3412
SUBROUTINE	REFRAC1	1988

Load Map for PROGRAM ION:

-PROGRAM-	---ADDRESS-
ION	000231
REFRAC	007632
PLOTNF	022314
PROFL1	023072
PROFL2	024252
BETA	026347
SICOUT	026633
DKSICO	026733
MAGFIN	027043
GK	030053
DKGK	030276
AUGOER$	030345
ABS$	030360
AMOD$	030363
SIGN$	030370
ALNLOGE	030374
ALOG10$	030433
ATAN$	030465
EXP$	030505
EXPE	030547
SINCOS$	030615
SQRT$	030672
SQRTE	030716
GETBA	030740
SIO$	030757
COS$	032372
SIN$	032424
ATANE	032456
SYSTEM$	032537
IFENDF$	033547
INPUTF$	033626
INPUTC$	034107
KODEP$	034236
KRAKER$	035652
OUTPTC$	037436
REWINM$	037532

--LABELED---COMMON--	
EVAL	000100
UPDT	000124
CORR	000215
EVAL	000100
UPDT	000124
CORR	000215

Load map for PROGRAM TABGEN:

```
-PROGRAM----ADDRESS-                        --LABELED---COMMON--
 TABGEN      0[illegible]100
 SICOUT      024332
 DKSICC      024432
 MAGFIN      024542
 GK          025652
 DKGK        025775
 ABS$        026044
 AMOD$       026047
 SIGN$       026054
 ATAN$       026060
 SINCOS$     026100
 SQRT$       026155
 SQRTE       026201
 GETBA       026223
 SIO$        026242
 COS$        027655
 SIN$        027707
 ATANE       027741
 SYSTEM$     030022
 ENDFIL$     031032
 IFENDF$     031103
 INPUTB$     031162
 INPUTC$     031443
 KODER$      031572
 KRAKER$     033206
 OUTPTB$     034772
 OUTPTC$     035251
 REWINM$     035345
```

Load map for PROGRAM ION1;

-PROGRAM-	-ADDRESS-
~~ION1~~	~~000171~~
~~REFRC1~~	~~006655~~
~~PROFL2~~	~~012561~~
BETA	014656
~~ABS$~~	~~015142~~
AMOD$	015145
~~FLOAT$~~	~~015152~~
ATAN$	015155
~~EXP$~~	~~015175~~
EXPE	015237
~~SINCOSE~~	~~015305~~
SQRT$	015362
~~SQRTE~~	~~015406~~
GETBA	015430
~~SIO$~~	~~01[illegible]447~~
COS$	017062
~~SIN$~~	~~017114~~
ATANE	017146
~~SYSTEM$~~	~~017227~~
IFENDF$	020237
~~INPUTE$~~	~~020316~~
INPUTC$	020577
KODER$	021726
KRAKER$	022342
OUTPTC$	024126
REWINM$	024222

--LABELED---COMMON--	
EVAL1	000100
CORR1	000115
~~EVAL1~~	000100
CORR1	000115

3.3.1 Data Base Characteristic - File Description

External data transfer in and out of the ionospheric model ION is handled through three files; the input data card deck read in PROGRAM ION, the input ionospheric coefficient tape read in SUBROUTINE REFRAC, and the output to the line printer is written in PROGRAM ION and SUBROUTINE PLOTNH.

Program	File Type	Mode	I/O	Fortran Unit No.	Description	Details Under
ION	Tape	BIN	I	1	Ionospheric coeff. tape	3.3.1.1
ION	Line printer	BCD	O	6	Output listing from ION	3.3.1.2
ION	Card reader	BCD	I	5	Input data deck to ION	3.3.1.3

The alternate version of the ionospheric program consists of two separate entities, the preprocessor TABGEN and the reduction program ION1. External data transfer in and out of TABGEN is handled through four files: an input data card deck, data output to line printer, the input ionospheric coefficient tape, and the output disc or tape file with f_0F2-h_r tables. External data transfer in and out of ION1 is handled through the following 3 data files: an input data card deck, the input data file with f_0F2-h_r tables, and output to the line printer.

Program	File Type	Mode	I/O	Fortran Unit No.	Description	Details Under
TABGEN	Tape	BIN	I	1	Ion. coeff. tape	3.3.1.1
TABGEN	Disc or tape	BIN	O	2	File with f_0F2-h_r tables	3.3.1.4
TABGEN	Line printer	BCD	O	6	Output listing from TABGEN	3.3.1.5
TABGEN	Card reader	BCD	I	5	Input data deck to TABGEN	3.3.1.6
ION1	Disc or tape	BIN	I	2	File with f_0F2-h_r tables	3.3.1.4
ION1	Card reader	BCD	I	5	Input data deck to ION1	3.3.1.8
ION1	Line printer	BCD	O	6	Output listing from ION1	3.3.1.7

3.3.1.1 Ionospheric Coefficient Tape

There are 36 fixed length records on the tape followed by a double end-of-file. Each record contains, in 3848 words, the generalized 10-day f_oF2 and 30-day M(3000)F2 coefficients to be used for one third of one month. The 36 records are in time sequence and valid for the periods January 1-10, January 11-20, January 21-31, February 1-10, February 11-20, February 21-28 or 29, ... , December 21-31.

Word	Mode	Fortran Name	Description
1	Integer	LOND	=(month×100+day), first date for which coefficients are valid
2	Integer	LONDY	=(month×100+day), last date for which coefficients are valid
3-2966	Real	WCOEF	Array of dimension 3×13×76 of generalized f_oF2 coefficients valid for the time interval specified by words 1 and 2
2967-3407	Real	UM	Array of dimension 9×49 of M(3000)F2 coefficients valid for a 12-month running average of the sunspot number = 0, and to be used for the time interval specified by words 1 and 2
3408-3848	Real	UM1	Array of dimension 9×49 of M(3000)F2 coefficients valid for a 12-month running average of the sunspot number = 100, and to be used for the time interval specified by words 1 and 2

The formation of the specific coefficient sets for f_oF2 and M(3000)F2 from the general coefficients is discussed under 3.2.1.1, CPC No. 2.

3.3.1.2 Line Printer Output Listing from ION

The typical output format of the results from ION is shown for some test cases under 4.1. In addition, the following error messages may occur:

Printed in PROGRAM ION, "Error in solar input data for year . . and month = . ." where upon the computer run is terminated.

Printed in PROGRAM ION, "Remaining update data not used"; if more than eight update conditions are supplied, the first eight are used, the remaining cards are skipped over.

Printed in SUBROUTINE REFRAC, "Coefficients not found on tape for year, month, day = ...", where upon control is transferred to PROGRAM ION to proceed with the next data case.

Printed in SUBROUTINE BETA, "Ray is reflected at ionosphere or near reflection condition, elevation angle correction is not computed," where upon control is transferred to SUBROUTINE REFRAC to proceed normal with the remaining computations.

3.3.1.3 Input Data Card Deck to ION

The input card deck to ION specifies the output and update options and it defines the evaluation and update conditions and the required solar data. The set up procedure for the card deck is described below followed by a description of the solar data and by the detailed card type and format information.

a) Procedure to Set Up Card Deck for ION

** Specify options **

Card type 1 : ISEL(1) - ISEL(5), output options for ionospheric profile and refraction corrections. =0 wanted, =1 not wanted.

Card type 2 : IUPDT, IDRDAV, update option and output option for correction to range differencing. =0 not wanted, =1 wanted. If =1, additional input data is required, cards 9 and 10 and/or card 11.

** Specify evaluation condition **

Card type 3 : FS, FLAT, FLON, station information: wave frequency, latitude and longitude. If refraction corrections are not desired, FS is not used and should be left blank or set =0 or positive.

Card type 4 : ELEV, AZ, HS, EDOT, HDOT, satellite information: elevation angle, azimuth, height, elevation rate, altitude rate. If the instantaneous range rate correction is not desired, EDOT and HDOT are not used and should be left blank or set to any value.

Card type 5 : IYR, MON, IDAY, TIME, time information: year, month, day, time.

** Specify solar data **

** If the year and month of this condition are the same as the year and month of the previous condition, skip cards 6, 7, 8.

Card type 6 : IYR, MON, FLX(1)-FLX(16), date and daily values of observed, solar flux for the first 16 days of the month. If future predictions are to be evaluated, leave array FLX blank.

Card type 7 : IYR, MON, FLX(17)-FLX(31), date and daily values of observed solar flux for the latter part of the month. If there are less than 31 days to the month, the additional spaces are normally left blank.

Card type 8 : IYR, MON, SIS, SIF, date and 12-month running average of sunspot number and solar flux.

Preparation of solar data is discussed under b).

** Specify update data **

** If update is not desired, IUPDT=0 on card 2, skip cards 9 and 10.

Card type 9 : NUPDT, number of observation conditions to be used for updating the predictions for the evaluation condition. Maximum = 8.

** If update is not desired for this particular evaluation condition, NUPDT=0, skip card 10.

Card type 10 : ULAT, ULON, ULEV, UZIM, UT, OBS, ITYPE, update data: latitude, longitude of observation station, elevation and azimuth of observation, observation time, value of measurement and type. When the observation is critical frequency set elevation to 90° and azimuth to 0°. For vertical and angular content use the appropriate angles.

** Repeat card 10 until all NUPDT conditions are defined.

** Specify additional data for range differencing **

** If corrections to range rate by differencing technique are not desired, IDRDAV = 0, skip card 11.

Card type 11 : ELEV, AZ, HS, TIME, satellite information, elevation, azimuth, and height and time information for the second observation used for the range differencing.

** Repeat cards 3 through 11 for any number of conditions desired.

** Terminate with card 3 containing a negative value for the wave frequency FS.

b) Preparation of Solar Data

The solar data can be extracted from the "Solar-Geophysical Data" monthly publications, issued by NOAA, Boulder, Colorado.

The daily values of solar flux are to be copied from the table "Daily Solar Indices" (normally page 7) under the column "Observed Flux Ottowa 2800" MHz (corresponds to 10.7 cm wavelength). If future predictions are to be evaluated and therefore no measurements available, the daily flux values required on card with the appropriate year and month are to be left blank. The program automatically checks for this condition and inserts the best estimate for the daily flux values which is the 12-month running average of the solar flux.

The 12-month running average $I_{12,j}$ for month j of a solar index I with a mean value $\overline{I}_k$ for month k is defined as,

$$I_{12,j} = \frac{1}{12}\left(\frac{\overline{I}_{j-6} + \overline{I}_{j+6}}{2} + \sum_{i=-5}^{+5} \overline{I}_{j+i}\right)$$

The monthly means of the index for the month under consideration, for 1 through 5 month past and prior and half the value of the monthly mean for 6 months past and prior are added and divided by 12, yielding an average over 12 months centered around the specified month. The 12-month running average (=smoothed) of the sunspot numbers $S_{12,j}$ for month j are listed in the "Solar Geophysical Data" publication (normally page 9) in table "Smoothed Observed and Predicted Sunspot Numbers" and are to be used for past as well as future evaluations.

The 12-month running average of the solar flux is computed from the accumulated monthly means using the formula above. The monthly means are listed along with the daily values of solar flux. If not enough advance data is available to form the 12-month running average, that value can be approximated with a 11.5, 10.5 or 9.5-month running average;

$$\text{approx. } F_{12,j} = F_{12.5-k,j} = \frac{1}{12.5-k}\left(\frac{\overline{F}_{j-6}}{2} + \sum_{i=-5}^{6-k} \overline{F}_{j+i}\right) \quad , k = 1, 2, \text{or } 3 \quad .$$

If not even enough data is available to form a 9.5-month running average, an estimate of the 12-month running average of the solar flux can be derived from the 12-month running average of the sunspot number for which tabulated predictions are available. The relationship between solar flux and sunspot number was arrived at by Stewart and Leftin, Reference 9.

$$\text{approx. } F_{12,j} = 63.75 + 0.728 \times S_{12,j} + 0.00089 \times S_{12,j}^2 \quad .$$

The attached tables contain the final 12-month running averages for sunspot number and solar flux from 1960 on and the monthly means for solar flux from 1970 on.

Table 1. 12-Month Running Average of the Zurich Relative Sunspot Number

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Jan.	128.9	80.2	45.2	29.4	19.5	11.7	27.7	75.0	102.6	110.0
Feb.	125.0	74.8	41.8	29.8	17.8	12.0	31.3	78.8	102.9	109.6
Mar.	121.6	68.8	39.8	29.7	15.4	12.5	34.5	82.2	104.7	108.0
Apr.	119.6	64.3	39.4	29.0	12.7	13.6	37.4	84.6	107.2	106.4
May	117.0	60.1	39.2	28.7	10.8	14.6	40.7	87.5	107.6	106.2
June	113.9	55.8	38.3	28.2	10.2	15.0	44.7	91.3	106.6	106.1
July	108.6	53.1	36.8	27.7	10.3	15.5	50.3	94.1	105.2	105.8
Aug.	102.4	52.5	34.9	27.2	10.2	16.4	56.6	95.3	104.8	106.4
Sept.	97.9	52.3	32.7	26.9	9.9	17.4	63.1	95.3	107.0	105.4
Oct.	93.3	51.4	30.8	26.0	9.6	19.7	67.6	95.0	109.9	104.1
Nov.	87.9	50.5	30.0	23.8	10.1	22.3	70.2	97.1	110.6	104.6
Dec.	83.7	48.7	29.8	21.3	11.0	24.5	72.7	100.6	110.1	104.9

	1970	1971	1972
Jan.	105.6	80.4	70.8
Feb.	106.0	77.8	71.2
Mar.	106.2	74.4	72.4
Apr.	106.1	70.9	73.4
May	105.8	68.1	72.9
June	105.3	66.7	70.5
July	103.8	65.5	68.1
Aug.	101.0	65.0	65.4
Sept.	97.2	66.4	62.0
Oct.	93.9	67.1	60.3
Nov.	89.4	67.6	58.5
Dec.	84.1	69.9	54.8

Table 2. 12-Month Running Average of the Solar Flux at 10.7 cm Wavelength (Ottowa)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Jan.	178.7	128.9	97.9	81.8	76.4	73.8	85.7	128.1	150.0	150.2
Feb.	174.6	124.1	95.2	81.8	75.5	74.4	88.4	131.5	149.4	150.2
Mar.	170.8	119.1	93.1	81.8	74.4	74.9	91.2	134.3	149.3	150.1
Apr.	168.6	115.1	91.7	81.5	73.3	75.4	93.8	136.3	150.4	150.0
May	166.2	110.8	91.1	81.2	72.5	75.8	96.5	138.8	150.8	150.8
June	162.9	106.6	90.4	81.0	72.2	76.0	100.1	141.7	149.9	151.4
July	157.8	103.7	89.2	80.6	72.3	76.4	104.6	145.0	147.8	151.4
Aug.	151.8	102.4	87.7	80.3	72.4	77.2	109.7	147.8	145.5	152.5
Sept.	147.4	102.0	85.8	80.1	72.2	78.3	115.3	148.2	146.0	152.8
Oct.	143.1	101.5	84.2	79.8	72.1	80.0	119.6	147.4	148.3	152.5
Nov.	137.9	101.1	83.1	78.7	72.5	81.9	122.8	147.9	149.0	153.7
Dec.	133.1	100.2	82.3	77.3	73.2	83.6	125.7	149.3	149.4	154.4

	1970	1971	1972
Jan.	154.7	135.0	120.5
Feb.	155.1	132.5	121.2
Mar.	155.2	129.9	122.1
Apr.	155.2	126.6	123.1
May	155.2	122.8	123.2
June	155.8	119.7	121.7
July	156.3	116.5	120.3
Aug.	155.0	114.7	118.0
Sept.	151.4	115.5	115.0
Oct.	147.6	116.1	113.5
Nov.	143.3	116.7	111.8
Dec.	138.6	118.9	108.6

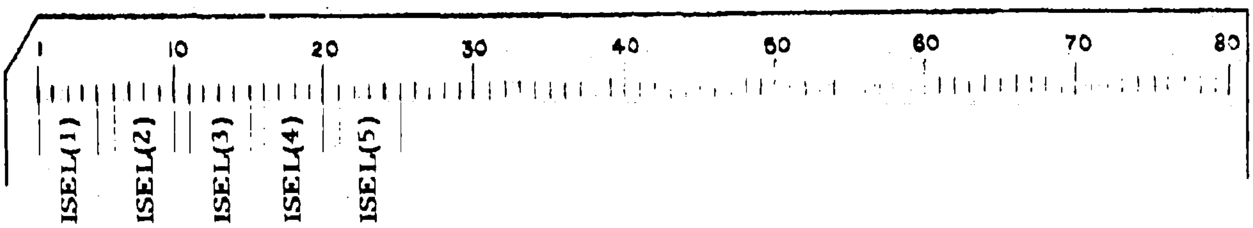
Table 3. Monthly Mean of the Solar Flux

	1970	1971	1972	1973
January	158.3	162.6	114.8	102.2
February	175.4	137.8	141.8	98.7
March	158.4	111.9	128.5	100.4
April	162.0	116.7	112.9	105.0
May	168.4	109.9	129.6	97.0
June	154.9	101.7	135.4	91.2
July	152.0	117.4	122.0	
August	138.2	114.1	125.7	
September	143.2	104.0	113.7	
October	148.3	107.2	121.1	
November	162.0	114.0	101.6	
December	152.8	124.5	102.9	

c) Card Type and Format Information

Card Type 1

Output options for ionospheric profile and refraction corrections

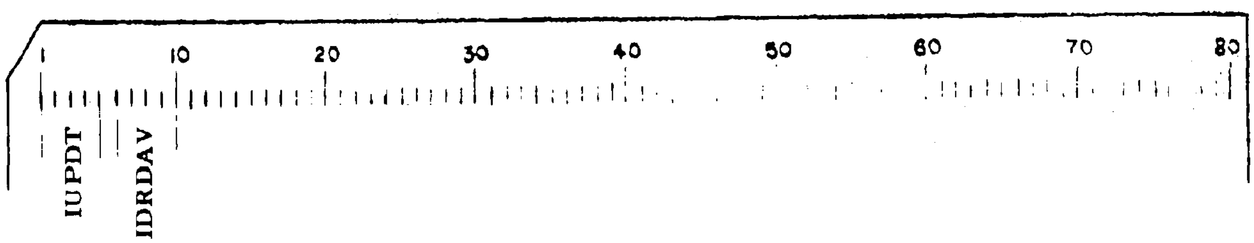


Format (5I5)

Word No.	Program Variable	Units	Format	Column	Description
1	ISEL(1)	--	I5	1-5	= 0 profile parameters and total content desired, =1 not desired
2	ISEL(2)	--	I5	6-10	= 0 profile plot desired, =1 not desired
3	ISEL(3)	--	I5	11-15	= 0 elevation angle correction desired, = 1 not desired
4	ISEL(4)	--	I5	16-20	= 0 range correction desired, = 1 not desired
5	ISEL(5)	--	I5	21-25	= 0 instantaneous range rate correction desired, = 1 not desired If words 1-5 above are all =1, only the critical frequency and corresponding height will be completed.

Card Type 2

Update option and output option for correction to range differencing

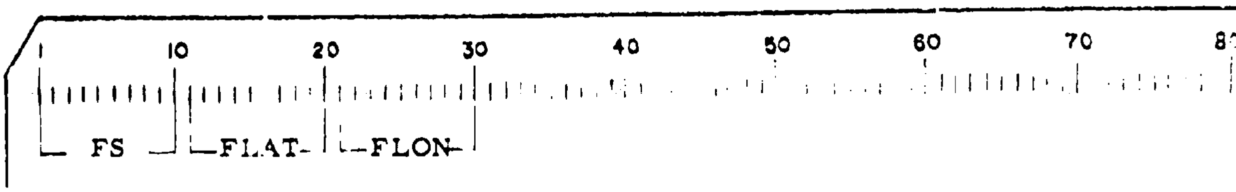


Format (2I5)

Word No.	Program Variable	Units	Format	Column	Description
1	IUPDT	--	I 5	1-5	Update flag: = 0 no update for any of following evaluation conditions, = 1 update in some or all of the following evaluation conditions
2	IDRDAV	--	I 5	6-10	Output option; = 0 correction to range rate obtained by differencing technique is not requested, = 1 desired

Card Type 3

Station data for evaluation condition

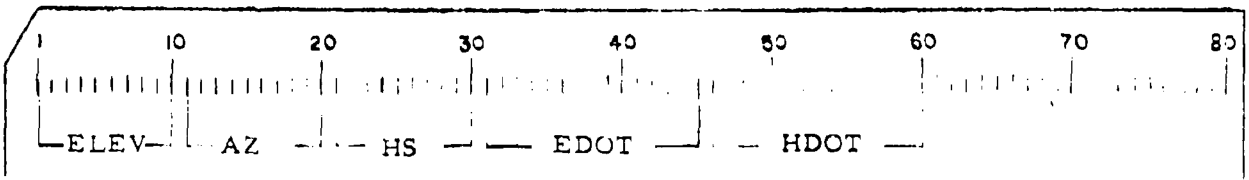


Format (F 10.4, 2F 10.5)

Word No.	Program Variable	Units	Format	Column	Description
1	FS	MHz	F10.4	1-10	Transmission frequency
2	FLAT	degrees	F10.5	11-20	Station latitude
3	FLON	degrees	F10.5	21-30	Station longitude (positive east, 0-360 degrees)

Card Type 4

Satellite data for evaluation condition

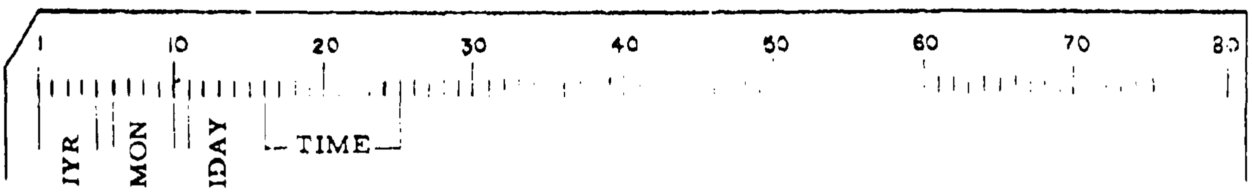


Format (2 F10.6, F10.0, 2D15.8)

Word No.	Program Variable	Units	Format	Column	Description
1	ELEV	degrees	F10.6	1-10	Elevation angle to satellite
2	AZ	degrees	F10.6	11-20	Azimuth angle
3	HS	km	F10.0	21-30	Height of satellite above surface of earth
4	EDOT	rad/sec	D15.8	31-45	Elevation rate
5	HDOT	m/sec	D15.8	46-60	Altitude rate

Card Type 5

Time data for evaluation condition

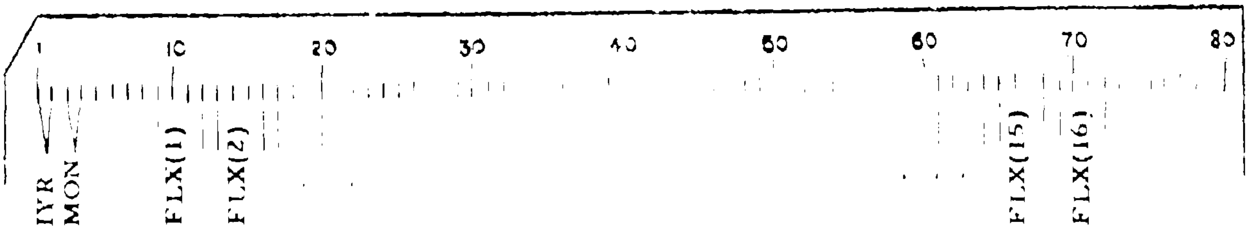


Format (3I5, F10.7)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 5	1-5	Year (last 2 digits)
2	MON	--	I 5	6-10	Month (=1 through 12)
3	IDAY	--	I 5	11-15	Day (=1 through 31)
4	TIME	hours	F10.7	16-25	Universal time

Card Type 6

Daily solar flux data for first part of month

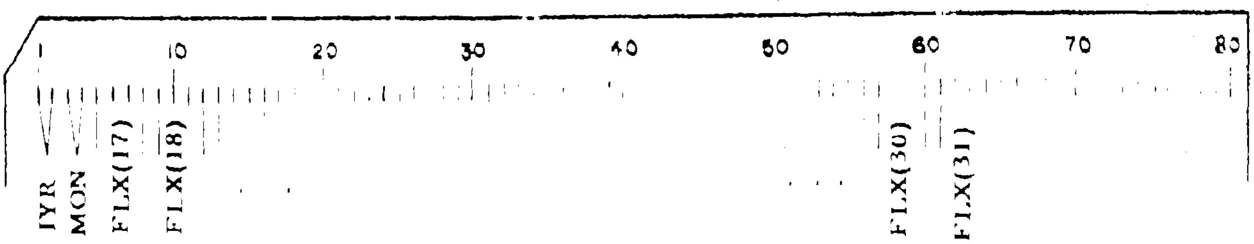


Format (2I2, 4x, 16I4)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 2	1-2	Year (last 2 digits)
2	MON	--	I 2	3-4	Month (=1 through 12)
3	FLX(1)	-	I 4	9-12	Daily solar flux x10 for day 1 of month
4	FLX(2)	--	I 4	13-16	Daily solar flux x10 for day 2 of month
.	.		.	.	.
.	.		.	.	.
.	.		.	.	.
18	FLX(16)	--	I 4	69-72	Daily solar flux x10 for day 16 of the month

Card Type 7

Daily solar flux data for second part of month

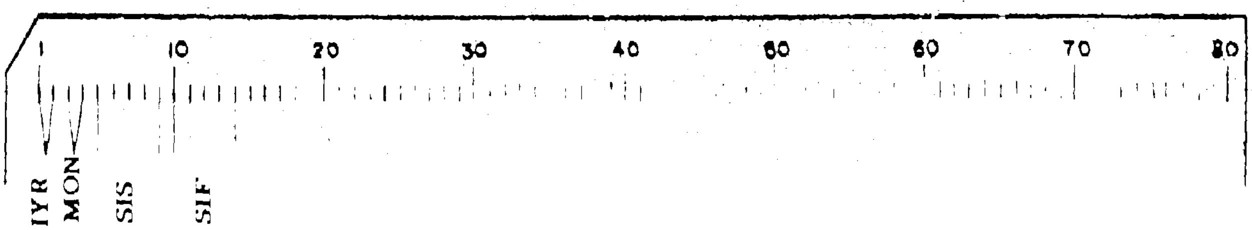


Format (2I2, 15I4)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	- -	I 2	1-2	Year (last 2 digits)
2	MON	- -	I 2	3-4	Month (= 1 through 12)
3	FLX(17)	- -	I 4	5-8	Daily solar flux x 10 for day 17 of month
4	FLX(18)	- -	I 4	9-12	Daily solar flux x 10 for day 18 of month
⋮	⋮			⋮	⋮
17	FLX(31)	-	I 4	61-64	Daily solar flux x10 for day 31 of month; if the month has less than 31 days, the spare locations are left blank

Card Type 8

Final or predicted 12-month running averages of sunspot number and solar flux

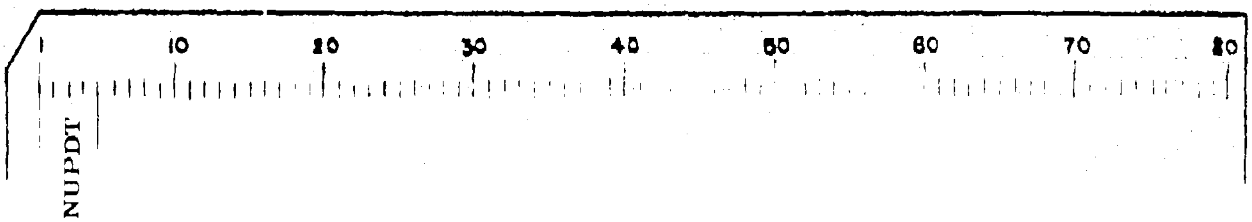


Format (2I2, 2I5)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 2	1-2	Year (last two digits)
2	MON	--	I 2	3-4	Month (= 1 through 12)
3	SIS	--	I 5	5-9	12-month running average of sunspot number x 10
4	SIF	--	I 5	10-14	12-month running average of solar flux x 10

Card Type 9

Update control constant

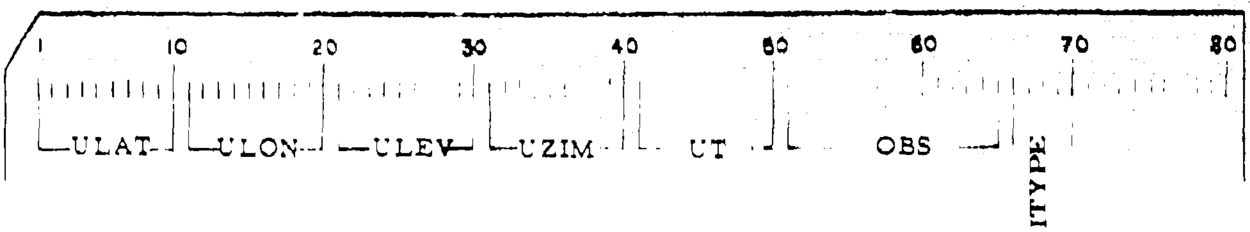


Format (I 5)

Word No.	Program Variable	Units	Format	Column	Description
1	NUPDT	--	I 5	1-5	Number of update conditions, maximum = 8

Card Type 10

Update data condition

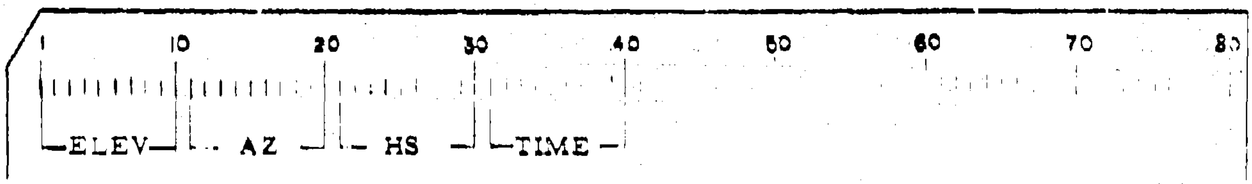


Format (2F10.5, 2F10.6, F10.7, D15.8, I 5)

Word No.	Program Variable	Units	Format	Column	Description
1	ULAT	degrees	F10.5	1-10	Latitude of update station
2	ULON	degrees	F10.5	11-20	Longitude of update station (positive east, 0-360 degrees)
3	ULEV	degrees	F10.6	21-30	Elevation angle of observation (=90 for f_oF2 data, = elevation to satellite for vertical and angular electron content)
4	UZIM	degrees	F10.6	31-40	Azimuth angle of observation
5	UT	hours	F10.7	41-50	Universal time of observation
6	OBS	MHz or e/m^2	D15.8	51-65	Observation to be used for update
7	ITYPE	--	I 5	66-70	Observation flag, = 1 for f_oF2, = 2 for vertical electron content, = 3 angular electron content

Card Type 11

Satellite and time information for second observation used for range differencing



Format (2F10.6, F10.0, F10.7)

Word No.	Program Variable	Units	Format	Column	Description
1	ELEV	degrees	F10.6	1-10	Elevation angle to satellite
2	AZ	degrees	F10.6	11-20	Azimuth angle
3	HS	km	F10.0	21-30	Height of satellite above surface of earth
4	TIME	hours	F10.7	31-40	Universal time

3.3.1.4 Ionospheric Data File with f_oF2-h_s Tables

The file with f_oF2-h_s tables is generated in PROGRAM TABGEN for use in the alternate ionospheric version PROGRAM ION1. It consists of fixed length records, as many as were generated in PROGRAM TABGEN, terminated by a single end-of-file. Each record contains, in 354 words, the date, the station position, the daily solar flux and values of critical frequency f_oF2 and corresponding height h_s. The values for f_oF2 and h_s are tabulated for the given date for 14 different times at each location of a 25 point pattern around the station which covers the ionosphere visible from that station.

Word	Mode	Fortran Name	Description
1	Integer	IYMD	Date: year × 10000 + month × 100 + day
2	Real	FLAT	Latitude of station in radians
3	Real	FLON	Longitude of station in radians
4	Real	FLUX	Value of daily solar flux (if the daily flux is greater than 130, the limit value of 130 is substituted)
5-354	Integer	IFH	Array of dimension 14×25 containing packed integer tabulated values for f_oF2 and h_s for 14 local time hours at each location of the 25 point pattern around the station. Each integer has 8 digits, the first 4 digits define h_s in units of $\frac{1}{10}$ km, the last 4 digits give f_oF2 in units of $\frac{1}{100}$ MHz.

3.3.1.5 Output Listing from TABGEN

The only line printer output from TABGEN is the printout of the input data conditions. In addition, the following error messages may occur:

Printed in PROGRAM TABGEN, "Error in solar input data for year = .. and month = ..", where upon the computer run is terminated.

Printed in PROGRAM TABGEN, "Coefficients not found on tape for year, month, day = ...", where upon the computer run is terminated.

3.3.1.6 Input Data Deck to TABGEN

The input to TABGEN consists of card type 12, shown on the next page containing date and station information and of card types 6, 7, 8 as described under 3.3.1.3 c) specifying the solar data.

Card type 12 : IYR, MON, IDAY, FLAT, FLON, year, month, day, latitude and longitude.

** If the year and month of this condition are the same as the year and month of the previous condition, skip cards 6, 7, 8.

Card type 6 : IYR, MON, FLX(1)-FLX(16), date and daily values of observed solar flux for the first 16 days of the month. If future predictions are to be evaluated, leave array FLX blank.

Card type 7 : IYR, MON, FLX(17)-FLX(31), date and daily values of observed solar flux for the latter part of the month. If there are less than 31 days to the month, the additional spaces are normally left blank.

Card type 8 : IYR, MON, SIS, SIF, date and 12-month running average of sunspot number and solar flux.

Preparation of the solar data is discussed under 3.3.1.3 b).

** Repeat cards 12, 6, 7, 8 for any number of conditions desired.

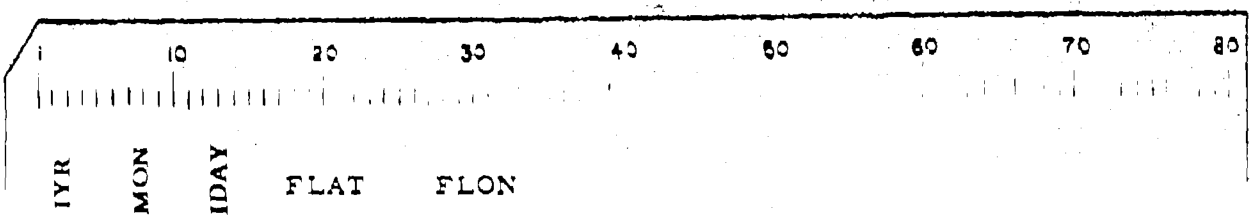
** Terminate with card 12 containing a zero or negative value for the year IYR.

3.3.1.7 Output Listing from ION1

The typical output format of the results from ION1 is shown for some test cases under Section 4.1. In addition, the following error messages may occur:

Card Type 12

Date and station evaluation condition



Format (3I5, 2F10.5)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 5	1-5	Year (last 2 digits)
2	MON	--	I 5	6-10	Month (=1 through 12)
3	IDAY	--	I 5	11-15	Day (=1 through 31)
4	FLAT	degrees	F10.5	16-25	Station latitude
5	FLON	degrees	F10.5	26-35	Station longitude (positive east, 0-360 degrees)

Printed in SUBROUTINE REFRC1, "f_oF2-h_s tables for this station and date not found in file," where upon control is transferred to PROGRAM ION1 to proceed with the next data case.

Printed in SUBROUTINE BETA, "Ray is reflected at ionosphere or near reflection condition, elevation angle correction is not computed," where upon control is transferred to SUBROUTINE REFRC1 to proceed normal with the remaining computations.

3.3.1.8 Input Data Deck to ION1

The input data to ION1 involves only card types 3, 4, and 5 as they are described under 3.3.1.3 c) to specify the evaluation condition.

Card type 3 : FS, FLAT, FLON, station information: wave frequency, latitude and longitude. Set FS=0 or positive, if refraction corrections are not requested.

Card type 4 : ELEV, AZ, HS, EDOT, HDOT, satellite information: elevation angle, azimuth, height, elevation rate, altitude rate. If the instantaneous range rate correction is not desired, EDOT and HDOT are not used and can be left blank or set to any value.

Card type 5 : IYR, MON, IDAY, TIME, time information: year, month, day, time.

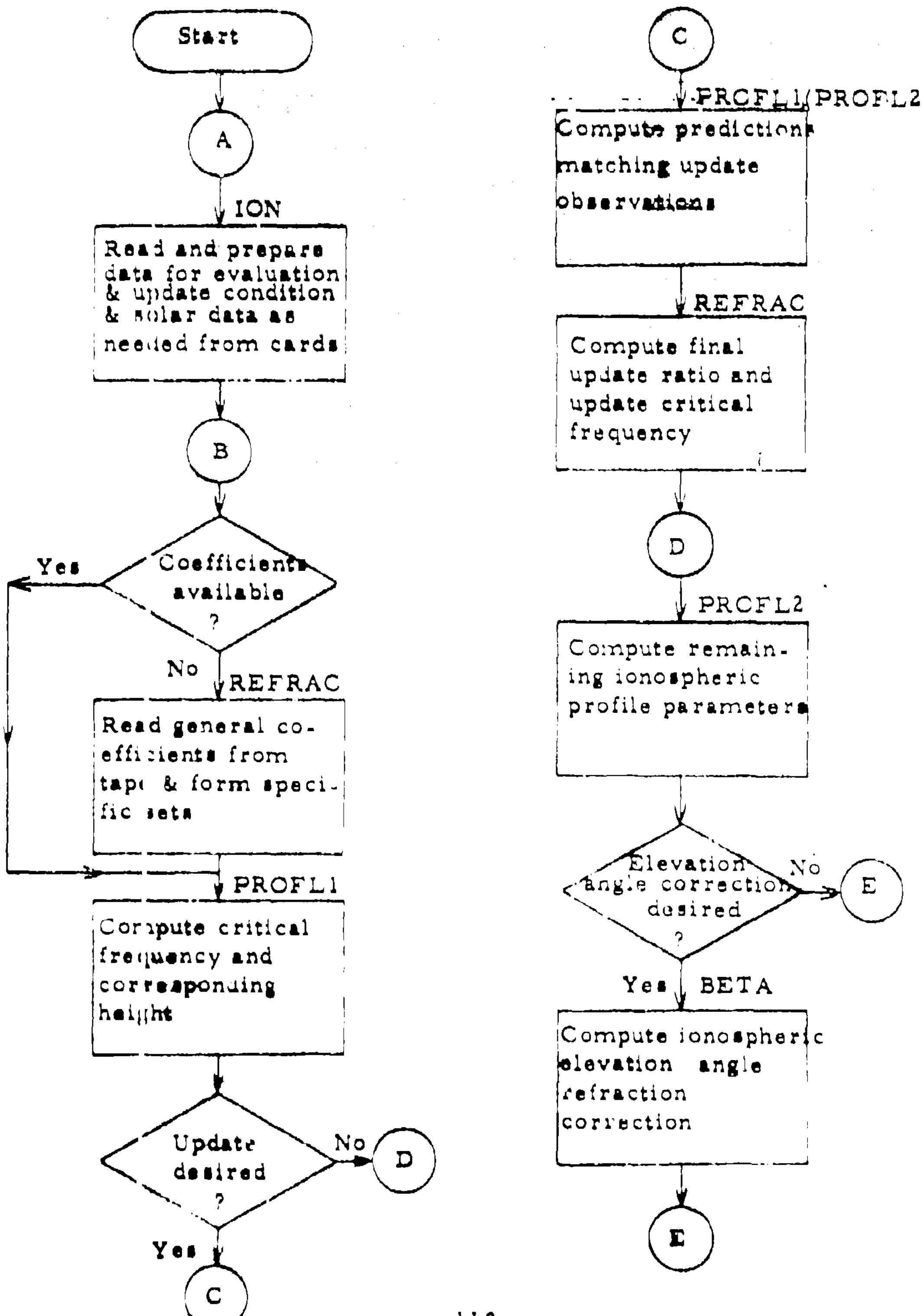
** Repeat cards 3 through 5 for any number of conditions desired.

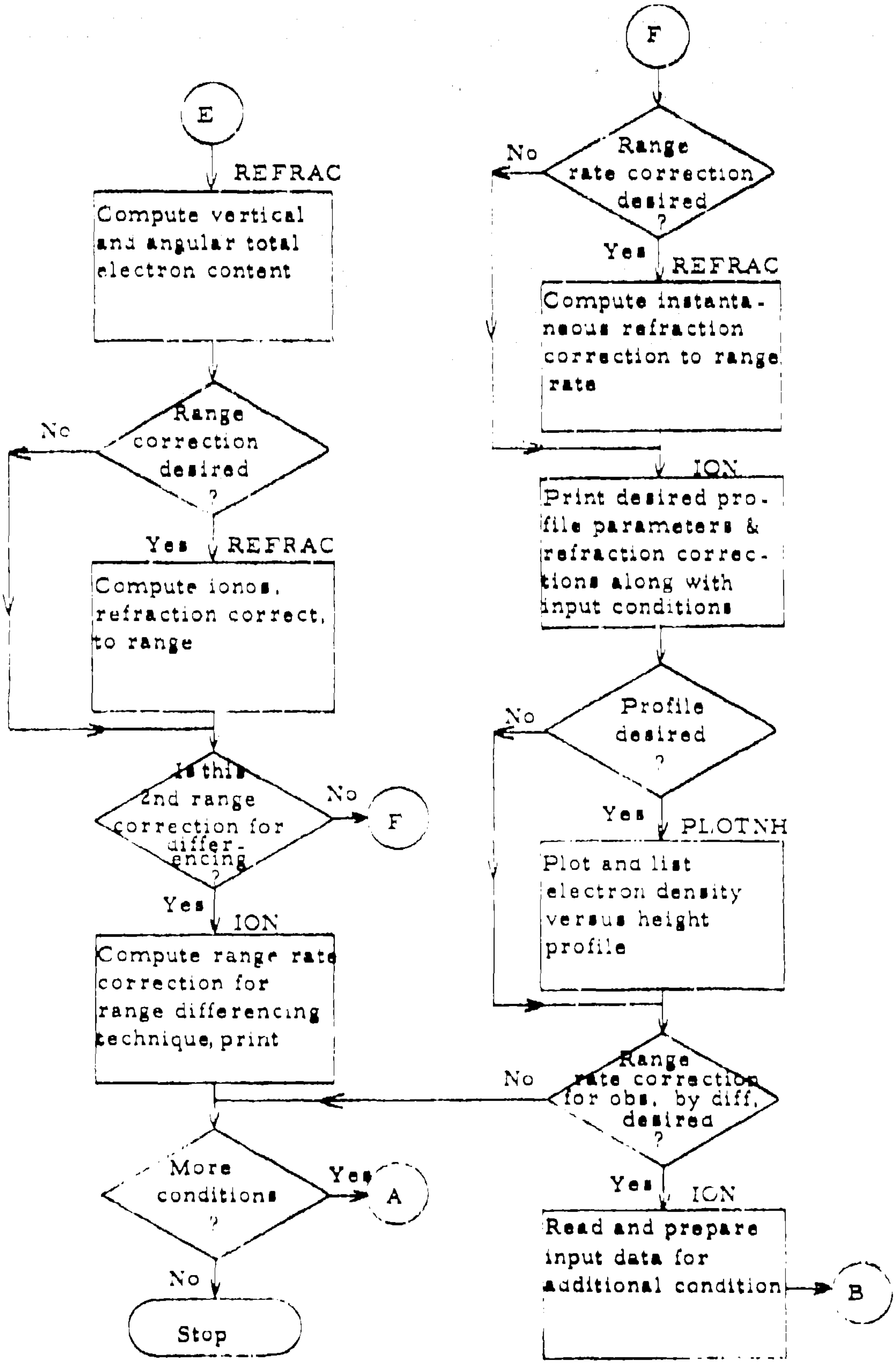
** Terminate with card 3 containing a negative value for the wave frequency FS.

3.4 Computer Program Functional Flow Diagram

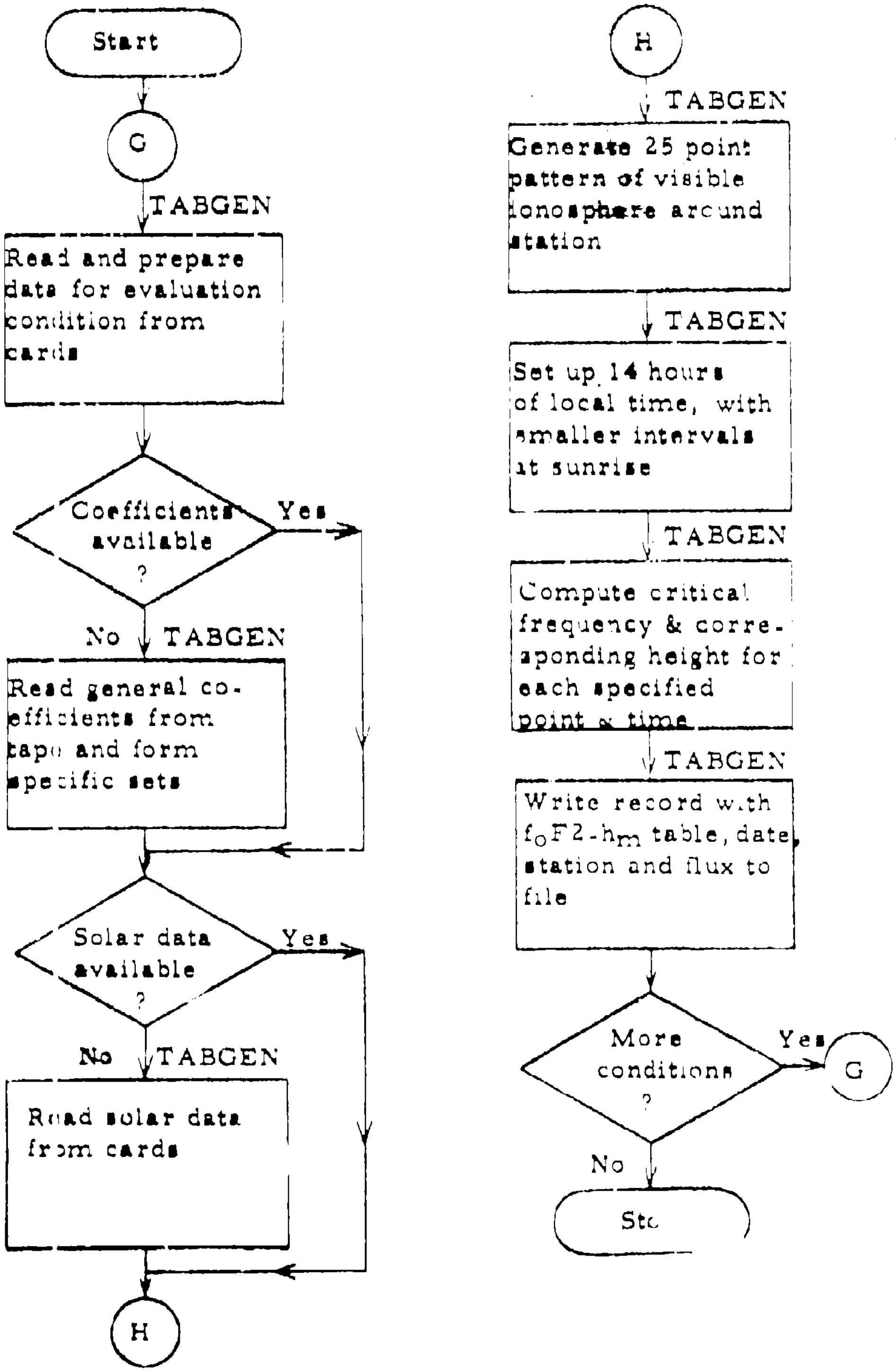
The functional flow diagram of the Bent Ionospheric Program ION is presented as well as the diagrams for the alternate version TABGEN-ION1. The labels to the right top of each block specify the program/subroutines that perform the function described in the block. Lower level flowcharts disclosing more details are listed under the individual computer program component descriptions in Section 3.2.1.2.

Functional Flow Diagram for ION

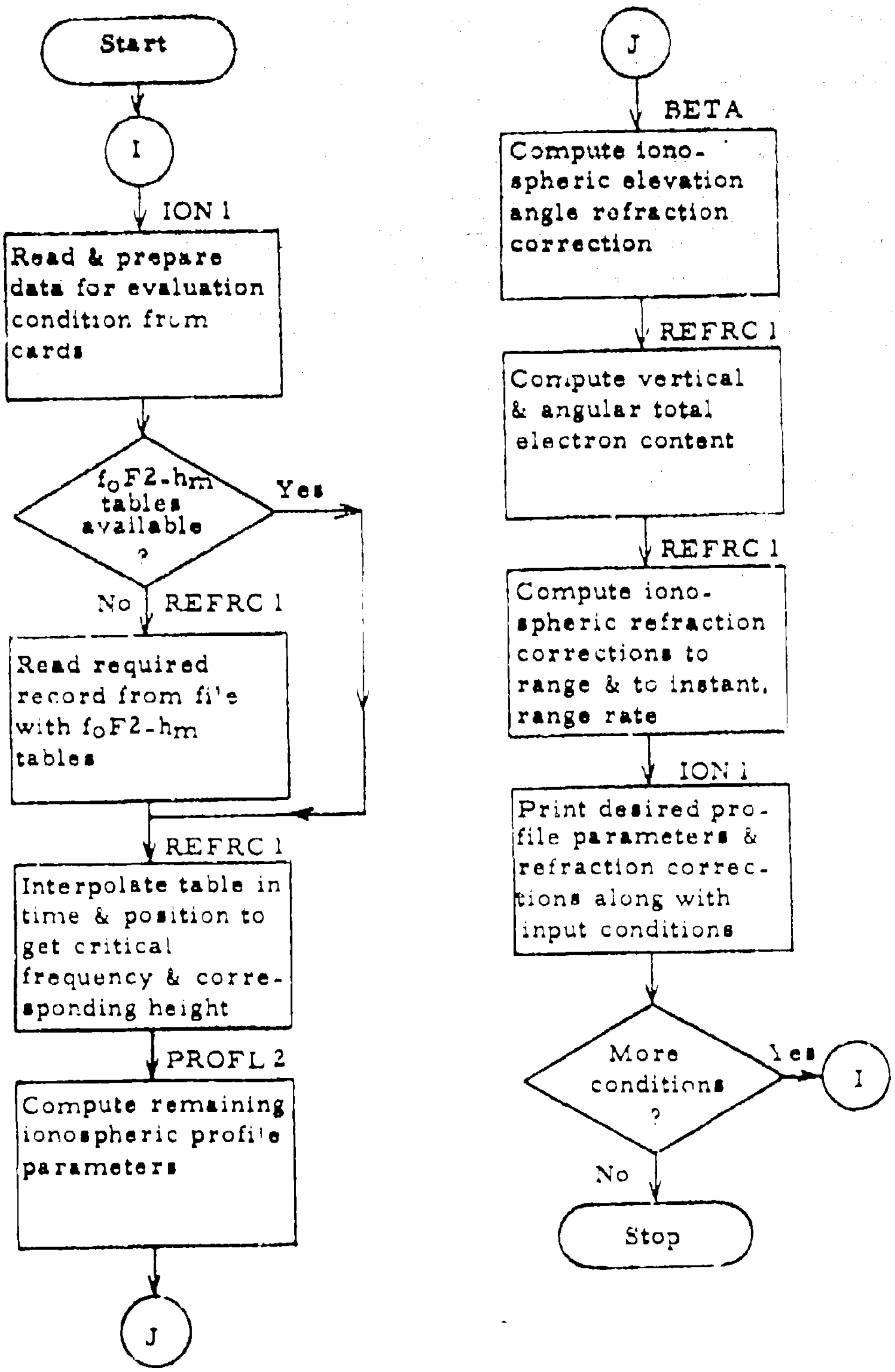



E
REFRAC
Compute vertical and angular total electron content
Range correction desired ?
No
Yes
REFRAC
Compute ionos. refraction correct. to range
Is this 2nd range correction for differencing ?
No
F
Yes
ION
Compute range rate correction for range differencing technique, print
More conditions ?
Yes
A
No
Stop
F
Range rate correction desired ?
No
Yes
REFRAC
Compute instantaneous refraction correction to range rate
ION
Print desired profile parameters & refraction corrections along with input conditions
Profile desired ?
No
Yes
PLOTNH
Plot and list electron density versus height profile
Range rate correction for obs. by diff. desired ?
No
Yes
ION
Read and prepare input data for additional condition
B

Functional Flow Diagram for TABGEN



Functional Flow Diagram for ION1



4.0 Quality Assurance

All aspects of the ionospheric model were tested thoroughly during and after the development phase and some of the results are shown in Section 6.2. The shape of the electron density versus height profile was compared with actual composite profiles compiled at NASA/GSFC and they were always in close agreement. The integrated electron content was compared extensively with the vertical electron content derived from Faraday rotation measurements. The results of this work performed for SAMSO, are described in Reference 2. The predictions alone accounted for 70 to 80% of the actual electron content and after updating with ionospheric observations, up to 90% of the ionosphere was estimated. The ionospheric refraction corrections were tested in orbit determination work performed at NASA/GSFC. The iterative least square reduction programs were run with and without ionospheric corrections and the final RMS values of the measurement residuals were greatly reduced by 30 to 75% upon use of ionospheric corrections.

After modifying the ionospheric program to its current form, a number of test cases were run and the results including all possible outputs were compared with results from previous runs before modifications. The same test cases listed under 4.1 should be checked out whenever the program is duplicated and transferred to another computer system to insure that all parts of the program are in working order.

4.1 Test Plan/Procedure

The following pages show a list of the input card deck and the corresponding printed output results for test cases 1 through 5 and a cross reference list in Table 4 of the various conditions tested. The five test cases evaluate the functions of the ionospheric program for various possibilities in latitude, longitude, local time, season, and solar activity effecting the ionospheric profile and therefore also electron content and refraction corrections. Each of the five test cases computes all possible output results; critical frequency

and corresponding height, the values of half thickness and the decay constants for the shape of the profile, the profile plot and list, vertical and angular electron content and refraction corrections to elevation angle, to range, to instantaneous range rate and to range differencing.

For the standard ionospheric PROGRAM ION the input is listed in Table 5 for all five test cases, and the ouput in Table 6. For the alternate version of the ionospheric program, the input and output of the preprocessor PROGRAM TABGEN are shown in Table 7 and the input and output of the reduction PROGRAM ION1 are given in Tables 8 and 9 respectively. Only test cases 1, 2, and 5 are presented for the alternate program since the update capability tested in cases 3 and 4 is not included in this version.

4.2 Other Quality Assurance Provisions

Whenever the program is reproduced for use on another system, the program card decks should be duplicated and verified. If the program is transferred to a system with compatible binary coding, the binary magnetic tape containing the ionospheric coefficients should be copied and verified. If the program is to be used on a computer with different binary word or record structure, the binary tape should be copied to a BCD tape and at the new location, transferred back onto a binary tape. Care should be taken that during the binary to BCD tape copy process no loss of significance will occur, which means the format (E17.11) is required for the general f_0F2 coefficients and the format (E14.8) is required for the general M(3000)F2 coefficients. The binary tape format is described under 3.3.1. When tape and card decks are available on the new system, the test runs described in 4.1 should be performed and the results compared with the output results in the tables for agreement.

Table 4. Cross Reference List of Conditions Examined in 5 Test Cases

Condition Tested	Case 1	Case 2	Case 3	Case 4	Case 5
Read coefficient data	yes	no	yes	no	yes
Read solar data	yes	no	yes	no	yes
Update with observations	no	no	single update	multiple update	no
Evaluate ionosphere for:					
Station latitude	low(-17°)	low(0°)	medium (35°)	medium (35°)	high (75°)
Station longitude	218°	355°	277°	277°	90°
Local time	evening (20^h)	morning (6^h)	noon (13^h)	noon (13^h)	night (1^h)
Season	summer (Aug)	summer (Aug)	autumn (Nov)	autumn (Nov)	winter (Feb)
Solar activity	high (Flux=181)	high (Flux=181)	medium(Flux=103)	medium(Flux=103)	low(Flux=79)
Elevation	low(5°)	med. high(60°)	med. low(31°)	med. low(31°)	high(90°)
Azimuth	180°	90°	208°	208°	350°
Height of satellite	med. (1000km)	low(500km)	high(200, 000km)	high(200, 000km)	med. (2000km)

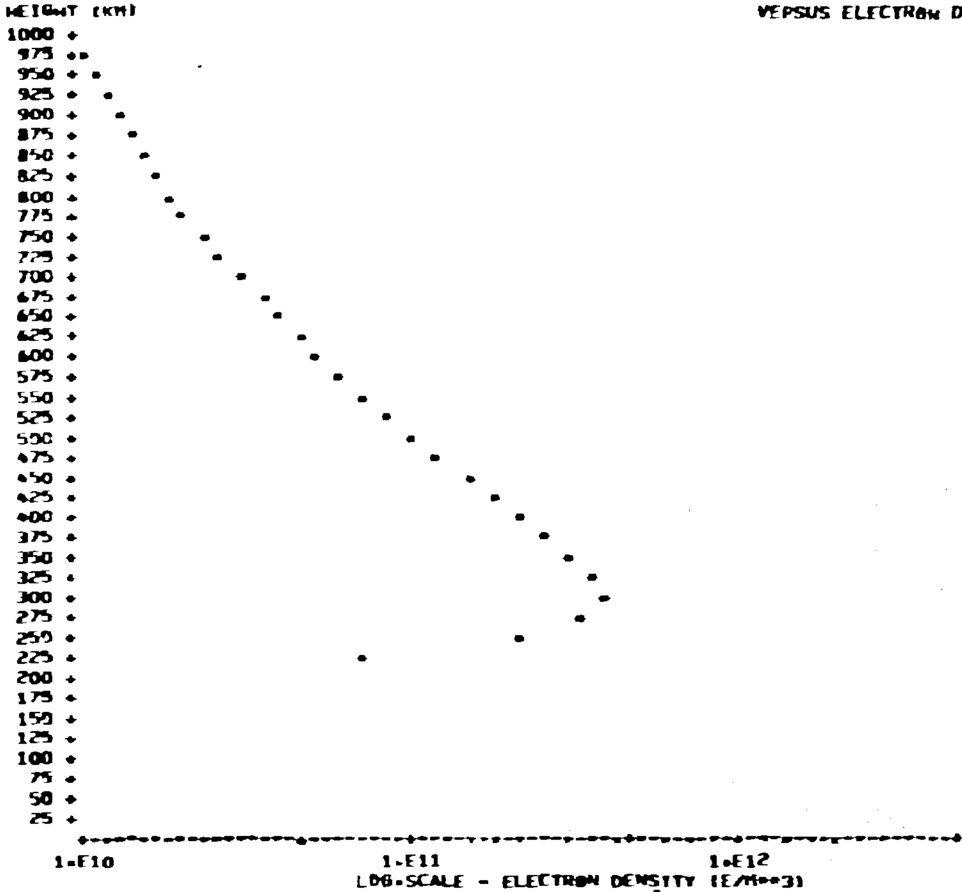
Table 5. Input Card Deck to PROGRAM ION, for 5 Test Cases

Test Case	Card Type	COLUMN: 1234567890123456789012345678901234567890123456789012345678901234567890123456789 0 (10, 20, 30, 40, 50, 60, 70, 80)
Initialization	1	0 0 C 0 0
	2	1 1
1	3	140.0000 -16.67000 218.00000
	4	5.000000150.000000 1000.-1.28709300E-03 0.00000000E 00
	5	68 8 15 6.
	6	680814221303130313681318132114381360137914271427146715741665180418101746
	7	6808165116081561156215501503134712801215115611211171119312321212
	8	6808 1048 1455
	9	0
	11	4.926255180.000000 1000. 6.0002778
2	3	140.0000 0.00000 355.00000
	4	60.000000 90.000000 500. -.01176329E 00 4.00000000E 02
	5	68 8 15 6.
	9	0
	11	59.326185 90.000000 500. 6.0002778
3	3	140.0000 35.19887 277.12420
	4	31.000000208.000000 200000. 1.45444104E-03 1.00000000E 02
	5	71 11 818.3000000
	6	711111401112113511711148118011151065102710361048106710481055105310341071
	7	7111107910661102115811771218123512481249132213171291120511 74
	8	7111 676 1167
	9	1
	10	37.90000 284.50000 90.000000 0.00000018.0000000 9.80000000E 00 1
	11	33.499473208. 200003.18.3083333
4	3	140.0000 35.19887 277.12420
	4	31.000000208.000000 200000. 1.45444104E-03 1.00000000E 02
	5	71 11 818.3000000
	9	3
	10	37.90000 284.50000 90.000000 0.00000019.00000010.0000000E 00 1
	10	40.00000 270.00000 60.000000140.00000018.5000000 3.00000000E 17 2
	10	40.00000 270.00000 60.000000140.00000019.0000000 4.50000000E 17 3
	11	33.499473208. 200003.18.3083333
5	3	140.0000 75.00000 90.00000
	4	90.000000350.000000 2000. 0.00000000E 00 0.20000000E 03
	5	64 2 2119.0000000
	6	6402 761 729 716 709 712 724 727 720 732 718 727 717 728 733 726 727 731
	7	6402 739 760 756 762 785 798 844 852 844 865 849 844 808 -10 -10
	8	6402 178 755
	9	0
	11	85.000000351.000000 2002.19.0027778
Termination	3	-1.

Table 62. Output Results from PROGRAM ION for 5 Test Cases - Case 1

```
** INPUT **

FREQUENCY= 140.0000 MHZ, LATITUDE= -16.67000 DEG, LONGITUDE OF STATION= 218.00300 DEG
ELEVATION= 5.000000 DEG, AZIMUTH=180.000000 DEG, HEIGHT OF SATELLITE= 1000.0 KM, ELEVATION RATE= -.12870930E-02 RAD/SEC
YEAR=68, MONTH= 8, DAY=15, U.TIME= 6.0000000 HRS,                                  ALTITUDE RATE= .00000000E 00 M/SEC
DAILY FLUX= 181.0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 145.5, OF SUNSPOT NUMBER= 104.8

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY            HM= 301.241 KM, CRITICAL FREQUENCY FOF2= 5.753 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT= [illegible]    ANGULAR NTA= .281039E 18 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA       YM= 100.480 KM, OF TOPSIDE PARABOLA YT= 100.480 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .75058E-05, MIDDLE K2= .53506E-05, UPPER K3= .34476E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .168138E 03 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE          = .577858E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE     = -.618566E 00 M/SEC
```

Table 6b. Output Results from PROGRAM ION for 5 Test Cases - Case 1 (continued)



HEIGHT (KM)	VERSUS ELECTRON DENSITY (E/M**3)	HEIGHT VS.	LL.DENSITY
1000	.95800 10	2000	.30480 09
975	.10440 11	1975	.33230 09
950	.11380 11	1950	.36220 09
925	.12410 11	1925	.39480 09
900	.13520 11	1900	.43030 09
875	.14740 11	1875	.46910 09
850	.16070 11	1850	.51130 09
825	.17510 11	1825	.55730 09
800	.19090 11	1800	.60750 09
775	.21260 11	1775	.66220 09
750	.24300 11	1750	.72180 09
725	.27780 11	1725	.78670 09
700	.31760 11	1700	.85750 09
675	.36300 11	1675	.93470 09
650	.41500 11	1650	.10190 10
625	.47440 11	1625	.11110 10
600	.54230 11	1600	.12110 10
575	.61990 11	1575	.13200 10
550	.72500 11	1550	.14380 10
525	.87460 11	1525	.15680 10
550	.10550 12	1500	.17090 10
475	.12730 12	1475	.18630 10
450	.15360 12	1450	.20300 10
425	.18530 12	1425	.22130 10
400	.22350 12	1400	.24120 10
375	.26560 12	1375	.26290 10
350	.32530 12	1350	.28660 10
325	.38740 12	1325	.31240 10
300	.41020 12	1300	.34050 10
275	.35630 12	1275	.37120 10
250	.22470 12	1250	.40460 10
225	.73870 11	1225	.44100 10
200	.00000 00	1200	.48070 10
175	.00000 00	1175	.52400 10
150	.00000 00	1150	.57120 10
125	.00000 00	1125	.62260 10
100	.00000 00	1100	.67860 10
75	.00000 00	1075	.73970 10
50	.00000 00	1050	.80630 10
25	.00000 00	1025	.87890 10

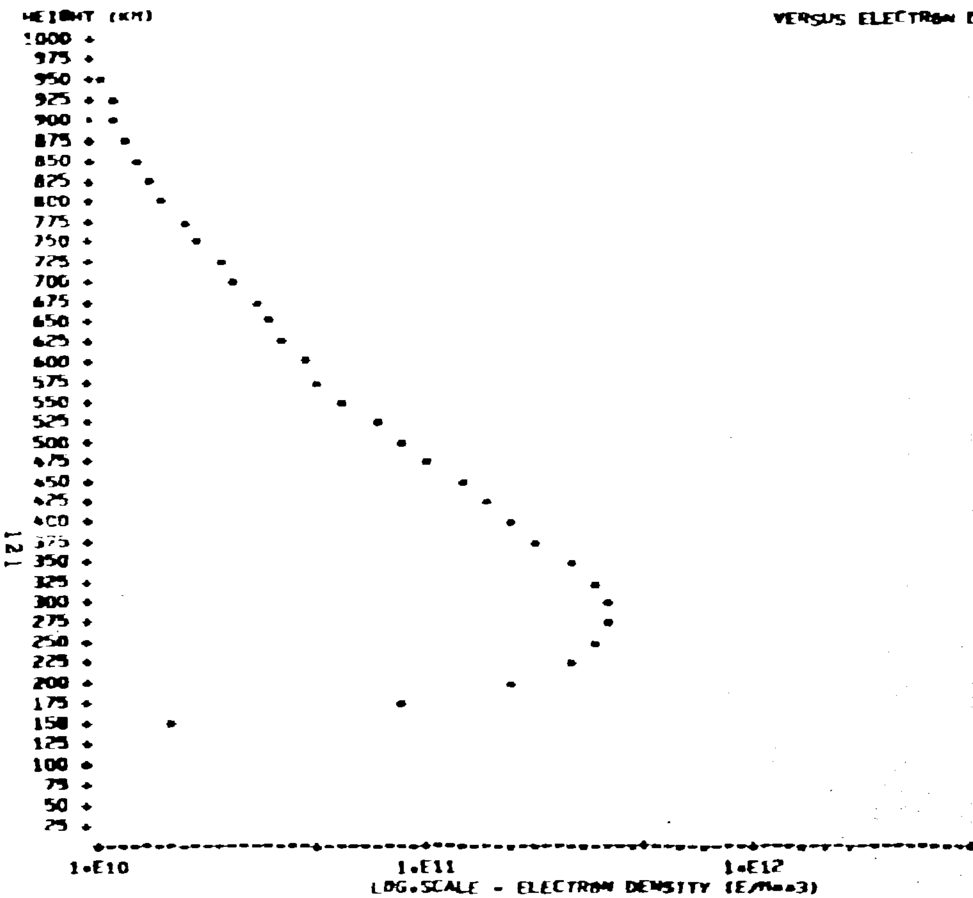
** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 4.926255 DEG, AZIMUTH=180.000000 DEG, HEIGHT= 1000.0 KM, U.TIME= 6.0002778 HRS

** OUTPUT **
RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 1.0001 SECONDS = .235271E 01 M/SEC

Table 6c. Output Results from PROGRAM ION for 5 Test Cases - Case 2

```
** INPUT **

FREQUENCY= 160.0000 MHZ, LATITUDE=    .00000 DEG, LONGITUDE OF STATION= 355.00000 DEG
ELEVATION= 60.000000 DEG, AZIMUTH= 90.000000 DEG, HEIGHT OF SATELLITE=     500.0 KM, ELEVATION RATE= -.11760290E-01 RAD/SEC
YEAR=68, MONTH= 8, DAY=15, U.TIME= 6.0000000 HRS,                                    ALTITUDE RATE=  .00000000E 03 M/SEC
DAILY FLUX= 181.0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 165.5, OF SUNSPOT NUMBER= 109.8

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY           HM= 278.308 KM,  CRITICAL FREQUENCY FOF2=  5.503 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .788791E 17 E/(M*M),   ANGULAR  NTA=  .598626E 17 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA      YM= 144.794 KM,  OF TOPSIDE PARABOLA  YT= 144.794 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .78089E-05, MIDDLE K2=  .50534E-05, UPPER K3=  .32812E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .368309E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE          =  .159765E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE     = -.120375E 01 M/SEC
```

Table 6d. Output Results from PROGRAM ION for 5 Test Cases - Case 2 (continued)



HEIGHT (KM)	ELECTRON DENSITY (E/M**3)	HEIGHT	EL.DENSITY
1000	.85320 10	2000	.32070 09
975	.92620 10	1975	.34810 09
950	.10050 11	1950	.37790 09
925	.10910 11	1925	.41020 09
900	.11850 11	1900	.44520 09
875	.12860 11	1875	.48330 09
850	.13960 11	1850	.52460 09
825	.15150 11	1825	.56940 09
800	.16450 11	1800	.61810 09
775	.18310 11	1775	.67100 09
750	.20770 11	1750	.72830 09
725	.23570 11	1725	.79060 09
700	.26740 11	1700	.85820 09
675	.30340 11	1675	.93150 09
650	.34430 11	1650	.10110 10
625	.39070 11	1625	.10980 10
600	.44330 11	1600	.11910 10
575	.50300 11	1575	.12930 10
550	.59700 11	1550	.14040 10
525	.72570 11	1525	.15240 10
500	.88220 1[illegible]	1500	.16540 10
475	.10720 12	1475	.17960 10
450	.13040 12	1450	.19490 10
425	.15850 12	1425	.21160 10
400	.19260 12	1400	.22970 10
375	.23410 12	1375	.24930 10
350	.28460 12	1350	.27060 10
325	.33450 12	1325	.29370 10
300	.36710 12	1300	.31880 10
275	.37520 12	1275	.34610 10
250	.34740 12	1250	.37570 10
225	.28060 12	1225	.40780 10
200	.18800 12	1200	.44270 10
175	.90520 11	1175	.48050 10
150	.17320 11	1150	.52160 10
125	.00000 00	1125	.56620 10
100	.00000 00	1100	.61460 10
75	.00000 00	1075	.66710 10
50	.00000 00	1050	.72410 10
25	.00000 00	1025	.78600 10

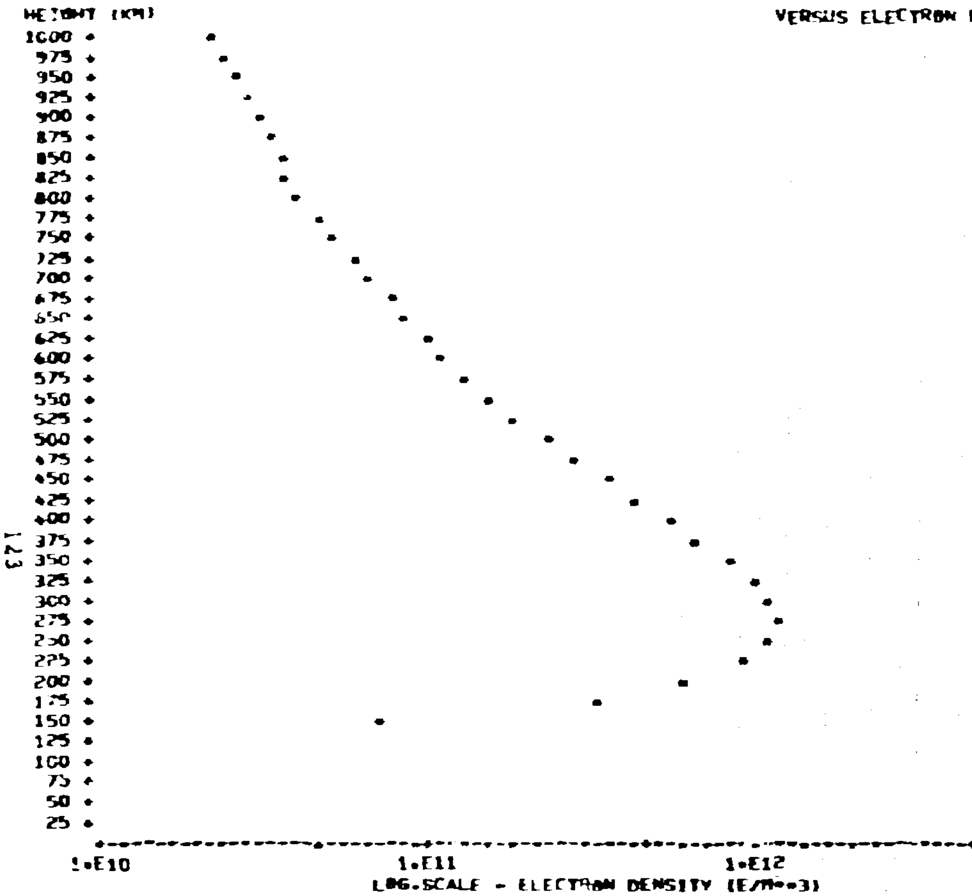
** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 59.326185 DEG, AZIMUTH= 90.000000 DEG, HEIGHT= 500.4 KM, U.TIME= 6.0302778 HRS

** OUTPUT **
RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 1.0001 SECONDS = -.166296E 01 M/SEC

Table 6e. Output Results from PROGRAM ION for 5 Test Cases - Case 3

```
** INPUT **

FREQUENCY=  140.0000 MHZ, LATITUDE=  35.19887 DEG, LONGITUDE OF STATION= 277.12420 DEG
ELEVATION= 31.000000 DEG,  AZIMUTH=208.000000 DEG,  HEIGHT OF SATELLITE=  200000.0 KM,  ELEVATION RATE=  .14544410E-02 RAD/SEC
YEAR=71, MONTH=11, DAY= 8,  U.TIME=18.3000000 HRS,                                       ALTITUDE RATE=  .10000000E 03 M/SEC
DAILY FLUX= 102.7, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 116.7, OF SUNSPOT NUMBER=  67.6

UPDATE DATA.
ILAT=  37.90300, LONG= 284.53000, ELEV= [illegible], AZIM=  .000000 DEG, UT=18.0000000 HRS,    OBSERVED FOF2=  .9800000E 01 MHZ

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY              HM= 274.152 KM,  CRITICAL FREQUENCY FOF2=  9.896 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .2961187E 18 E/(M*M),   ANGULAR  NTA=  .5459837E 18 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA     YM= 143.516 KM,  OF TOPSIDE PARABOLA  YT= 143.516 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .85456E-05, MIDDLE K2=  .52206E-05, UPPER K3=  .29298E-03 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .7834057E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE           =  .1068855E 04 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE      =  .1543294E 01 M/SEC
```

Table 6f. Output Results from PROGRAM ION for 5 Test Cases - Case 3 (continued)



VERSUS ELECTRON DENSITY (E/M**3)

---	.23330 11
---	.25100 11
---	.27010 11
---	.29060 11
---	.31270 11
---	.33650 11
---	.36210 11
---	.38960 11
---	.41920 11
---	.46550 11
---	.53040 11
---	.60440 11
---	.68870 11
---	.78470 11
---	.89410 11
---	.10190 12
---	.11610 12
---	.13230 12
---	.15880 12
---	.19670 12
---	.24360 2
---	.30180 12
---	.37390 12
---	.46320 12
---	.57380 12
---	.71080 12
---	.89060 12
---	.10620 13
---	.11750 13
---	.12140 13
---	.11470 13
---	.94630 12
---	.65260 12
---	.33180 12
---	.76900 11
---	.00000 00
---	.00000 00
---	.00000 00
---	.00000 00
---	.00000 00

HEIGHT VS.	EL.DENSITY
2000 ---	.12460 10
1975 ---	.13410 10
1950 ---	.14430 10
1925 ---	.15520 10
1900 ---	.16700 10
1875 ---	.17970 10
1850 ---	.19340 10
1825 ---	.20810 10
1800 ---	.22390 10
1775 ---	.24090 10
1750 ---	.25920 10
1725 ---	.27890 10
1700 ---	.30010 10
1675 ---	.32290 10
1650 ---	.34740 10
1625 ---	.37380 10
1600 ---	.40230 10
1575 ---	.43280 10
1550 ---	.46570 10
1525 ---	.50110 10
1500 ---	.53920 10
1475 ---	.58020 10
1450 ---	.62430 10
1425 ---	.67170 10
1400 ---	.72270 10
1375 ---	.77770 10
1350 ---	.83680 10
1325 ---	.90040 10
1300 ---	.96880 10
1275 ---	.10420 11
1250 ---	.11220 11
1225 ---	.12070 11
1200 ---	.12990 11
1175 ---	.13970 11
1150 ---	.15030 11
1125 ---	.16180 11
1100 ---	.17410 11
1075 ---	.18730 11
1050 ---	.20150 11
1025 ---	.21680 11

** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 33.499473 DEG, AZIMUTH=208.000000 DEG, HEIGHT= 200003.0 KM, U.TIME=18.3083333 HRS

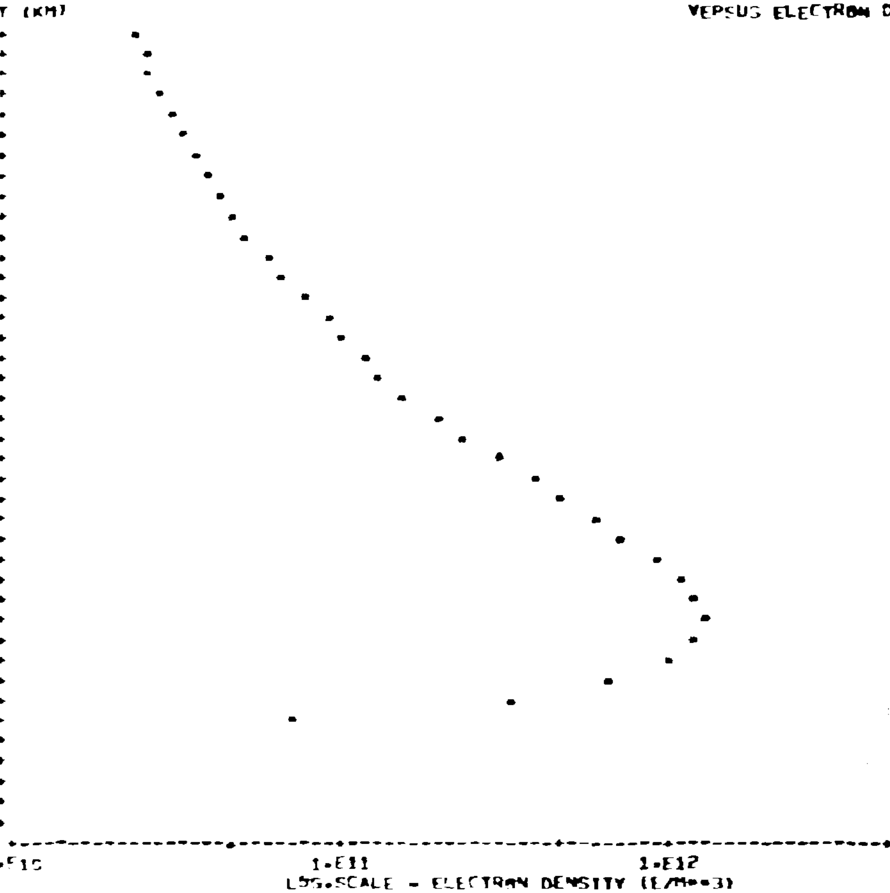
** OUTPUT **
RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 29.9999 SECONDS = .184114E 01 M/SEC

Table 6g. Output Results from PROGRAM ION for 5 Test Cases - Case 4

```
** INPUT **

FREQUENCY= 140.0000 MHZ, LATITUDE= 35.19687 DEG, LONGITUDE OF STATION= 277.12420 DEG
ELEVATION= 31.000000 DEG, AZIMUTH=208.000000 DEG, HEIGHT OF SATELLITE= 200000.0 KM, ELEVATION RATE= .14544410E-02 RAD/SEC
YEAR=71, MONTH=11, DAY= 8, U.TIME=18.3000000 HRS, ALTITUDE RATE= .10000000E 03 M/SEC
DAILY FLUX= 102.7, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 116.7, OF SUNSPOT NUMBER= 67.6

UPDATE DATA=
1)LAT= 37.90000, LONG= 284.50000, ELEV= 90.000000, AZIM= .000000 DEG, UT=19.0000000 HRS, OBSERVED FOF2= .10000000E 02 MHZ
2)LAT= 40.00000, LONG= 270.00000, ELEV= 60.000000, AZIM=140.000000 DEG, UT=18.5000000 HRS, OBS.VERT.CONTENT= .30000000E 18 E/M2
3)LAT= 40.00000, LONG= 270.00000, ELEV= 60.000000, AZIM=140.000000 DEG, UT=19.0000000 HRS, OBS.ANGL.CONTENT= .45000000E 18 E/M2


** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY              HM= 274.152 KM, CRITICAL FREQUENCY FOF2= 10.217 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT= .312175E 18 E/(M*M),  ANGULAR NTA= .547898E 18 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA      YM= 142.298 KM, OF TOPSIDE PARABOLA YT= 142.298 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .86825E-05, MIDDLE K2= .52597E-05, UPPER K3= .29129E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .826693E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE          = .112655E 04 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE     = .204814E 01 M/SEC
```

Table 6h. Output Results from PROGRAM ION for 5 Test Cases Case 4 (continued)

HEIGHT (KM) VERSUS ELECTRON DENSITY (E/M**3)



HEIGHT (KM)		VERSUS ELECTRON DENSITY (E/M**3)	HEIGHT	VS.	EL.DENSITY
1000	---	.2401D 11	2000	---	.1304D 10
975	---	.2582D 11	1975	---	.1403D 10
950	---	.2777D 11	1950	---	.1509D 10
925	---	.2987D 11	1925	---	.1623D 10
900	---	.3213D 11	1900	---	.1745D 10
875	---	.3456D 11	1875	---	.1877D 10
850	---	.3716D 11	1850	---	.2019D 10
825	---	.3997D 11	1825	---	.2171D 10
800	---	.4299D 11	1800	---	.2335D 10
775	---	.4775D 11	1775	---	.2512D 10
750	---	.5446D 11	1750	---	.2701D 10
725	---	.6211D 11	1725	---	.2905D 10
700	---	.7084D 11	1700	---	.3125D 10
675	---	.8079D 11	1675	---	.3361D 10
650	---	.9214D 11	1650	---	.3615D 10
625	---	.1051D 12	1625	---	.3888D 10
600	---	.1139D 12	1600	---	.4182D 10
575	---	.1367D 12	1575	---	.4497D 10
550	---	.1643D 12	1550	---	.4837D 10
525	---	.2042D 12	1525	---	.5203D 10
500	---	.2537D 12	1500	---	.5596D 10
475	---	.3152D 12	1475	---	.6018D 10
450	---	.3916D 12	1450	---	.6473D 10
425	---	.4865D 12	1425	---	.6962D 10
400	---	.6044D 12	1400	---	.7488D 10
375	---	.7510D 12	1375	---	.8053D 10
350	---	.9330D 12	1350	---	.8662D 10
325	---	.1129D 13	1325	---	.9316D 10
300	---	.1252D 13	1300	---	.1002D 11
275	---	.1294D 13	1275	---	.1078D 11
250	---	.1221D 13	1250	---	.1159D 11
225	---	.1054D 13	1225	---	.1247D 11
200	---	.6869D 12	1200	---	.1341D 11
175	---	.3426D 12	1175	---	.1442D 11
150	---	.7380D 11	1150	---	.1551D 11
125	---	.0000D 00	1125	---	.1668D 11
100	---	.0000D 00	1100	---	.1794D 11
75	---	.0000D 00	1075	---	.1930D 11
50	---	.0000D 00	1050	---	.2075D 11
25	---	.0000D 00	1025	---	.2232D 11

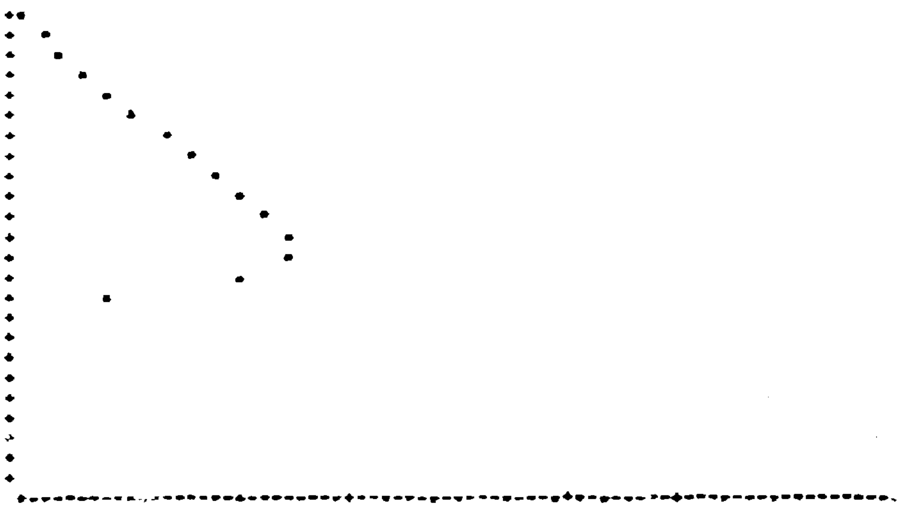
** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 33.439473 DEG, AZIMUTH=208.000000 DEG, HEIGHT= 200003.0 KM, U-TIME=18.3083333 HRS

** OUTPUT ** RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 29.9999 SECONDS = .198257E 01 M/SEC

Table 61. Output Results from PROGRAM ION for 5 Test Cases - Case 5

```
** INPUT **

FREQUENCY=  140.0000 MHZ, LATITUDE=  75.00000 DEG, LONGITUDE OF STATION=  90.00000 DEG
ELEVATION= 90.000000 DEG,  AZIMUTH=350.000000 DEG,  HEIGHT OF SATELLITE=     2000.0 KM,  ELEVATION RATE=  .00000000E 00 RAD/SEC
YEAR=64, MONTH= 2, DAY=21,  U-TIME=19.0000000 HRS,                                          ALTITUDE RATE=  .20000000E 03 M/SEC
DAILY FLUX=  75.5, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX=  75.5, OF SUNSPOT NUMBER=  17.8

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY           HM= 310.608 KM,  CRITICAL FREQUENCY FOF2=  2.343 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .154534E 17 E/(M*M),   ANGULAR  NTA=  .154534E 17 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA     YM=  87.237 KM,  OF TOPSIDE PARABOLA  YT=  87.237 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .79515E-05, MIDDLE K2=  .46440E-05, UPPER K3=  .23456E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .434671E-02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE          =  .317741E 02 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE     = -.106845E-03 M/SEC
```

Table 6j. Output Results from PROGRAM ION for 5 T Cases - Case 5 (continued)



HEIGHT (KM)		VERSUS ELECTRON DENSITY (E/M**3)	HEIGHT	VS.	EL.DENSITY
1000	---	.27130 10	2000	---	.25980 09
975	---	.28760 10	1975	---	.27550 09
950	---	.30500 10	1950	---	.29220 09
925	---	.32340 10	1925	---	.30980 09
900	---	.34300 10	1900	---	.32850 09
875	---	.36370 10	1875	---	.34830 09
850	---	.38560 10	1850	---	.36940 09
825	---	.40890 10	1825	---	.39170 09
800	---	.43360 10	1800	---	.41540 09
775	---	.47210 10	1775	---	.44040 09
750	---	.53020 10	1750	---	.46700 09
725	---	.59540 10	1725	---	.49520 09
700	---	.66870 10	1700	---	.52520 09
675	---	.75110 10	1675	---	.55690 09
650	---	.84350 10	1650	---	.59050 09
625	---	.94740 10	1625	---	.62620 09
600	---	.10640 11	1600	---	.66400 09
575	---	.11950 11	1575	---	.70410 09
550	---	.13780 11	1550	---	.74640 09
525	---	.16430 11	1525	---	.79170 09
500	---	.19600 11	1500	---	.83950 09
475	---	.23380 11	1475	---	.89020 09
450	---	.27890 11	1450	---	.94400 09
425	---	.33260 11	1425	---	.10010 10
400	---	.39670 11	1400	---	.10610 10
375	---	.47320 11	1375	---	.11260 10
350	---	.56450 11	1350	---	.11940 10
325	---	.66210 11	1325	---	.12660 10
300	---	.66070 11	1300	---	.13420 10
275	---	.47270 11	1275	---	.14230 10
250	---	.18220 11	1250	---	.15090 10
225	---	.93160 08	1225	---	.16000 10
200	---	.00000 00	1200	---	.16970 10
175	---	.00000 00	1175	---	.17990 10
150	---	.00000 00	1150	---	.19080 10
125	---	.00000 00	1125	---	.20230 10
100	---	.00000 00	1100	---	.21450 10
75	---	.00000 00	1075	---	.22750 10
50	---	.00000 00	1050	---	.24120 10
25	---	.00000 00	1025	---	.25580 10

** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
FLEVATION= 85.000000 DEG, AZIMUTH=351.000000 DEG, HEIGHT= 2002.0 KM, U.TIME=19.0027778 HRS

** OUTPUT **
RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 10.0001 SECONDS = -.293044E-01 M/SEC

Table 7. Input Card Deck and Output Results for Preprocessor PROGRAM TABGEN for 3 Test Cases

Test Case#	Card Type	COLUMN: 1234567890123456789012345678901234567890123456789012345678901234567890123456789 0 (10, 20, 30, 40, 50, 60, 70, 80)
1	12	68 8 15 -16.67000 218.00000
	6	68081421130313031368131813211438136013791427142714671574166518041810174 6
	7	68081651160815611562155015031347128012151156112111711193123212 12
	8	6808 1048 1455
2	12	68 8 15 0.00000 355.00000
5	12	64 2 21 75.00000 90.00000
	6	6402 761 729 716 709 712 724 727 720 732 718 727 717 728 733 726 727 731
	7	6402 739 760 756 762 785 798 844 852 844 865 849 844 808 -10 -10
	8	6402 178 755
Termination	12	0

Line Printer Output

Case 1 - GENERATE RECORD ON OUTPUT TAPE CONTAINING IONOSPHERIC FOF2-HM TABLES FOR
YEAR=68, MONTH= 8, DAY=15, LATITUDE= -16.67000 DEG, LONGITUDE OF STATION= 218.00000 DEG
DAILY FLUX= 181.0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 145.5, OF SUNSPOT NUMBER= 104.8

Case 2 - GENERATE RECORD ON OUTPUT TAPE CONTAINING IONOSPHERIC FOF2-HM TABLES FOR
YEAR=68, MONTH= 8, DAY=15, LATITUDE= .00000 DEG, LONGITUDE OF STATION= 355.00000 DEG
DAILY FLUX= 181.0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 145.5, OF SUNSPOT NUMBER= 104.8

Case 5 - GENERATE RECORD ON OUTPUT TAPE CONTAINING IONOSPHERIC FOF2-HM TABLES FOR
YEAR=64, MONTH= 2, DAY=21, LATITUDE= 75.00000 DEG, LONGITUDE OF STATION= 90.00000 DEG
DAILY FLUX= 78.5, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 75.5, OF SUNSPOT NUMBER= 17.8

Table 8. Input Card Deck to PROGRAM ION1 for 3 Test Cases

Test Case#	Card Type	COLUMN: 1234567890 10	1234567890 20	1234567890 30	1234567890 40	1234567890 50	1234567890 60	1234567890 70	1234567890 80
1	3	140.0000	-16.67000	218.00000					
	4	5.000000	180.000000	1000.	-1.28709300E-03	0.00000000E 00			
	5	68 8	15 6.						
2	3	140.0000	0.00000	355.00000					
	4	60.000000	90.000000	500.	-.01176029E 00	4.00000000E 02			
	5	68 3	15 6.						
5	3	140.0000	75.00000	90.00000					
	4	90.000000	350.000000	2000.	0.00000000E 00	0.20000000E 03			
	5	64 3	2119.0000000						
Termination	3	-1.							

Table 9. Output Results from PROGRAM ION1 for 3 Test Cases

Case 1

```
** INPUT **

FREQUENCY=  140.0000 MHZ, LATITUDE= -16.67000 DEG, LONGITUDE OF STATION= 218.00000 DEG
ELEVATION=  5.000000 DEG,  AZIMUTH=180.000000 DEG,  HEIGHT OF SATELLITE=     1000.0 KM,  ELEVATION RATE= -.12870930E-02 RAD/SEC
YEAR=68, MONTH= 8, DAY=15,  J.TIME= 6.0000000 HRS,                                         ALTITUDE RATE=  .00000000E 00 M/SEC

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY              HM= 301.295 KM,  CRITICAL FREQUENCY FOF2=  5.923 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .915508E 17 E/(M*M),   ANGULAR  NTA=  .296724E 18 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA     YM= 100.359 KM,  OF TOPSIDE PARABOLA  YT= 100.359 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .75429E-05, MIDDLE K2=  .54027E-05, UPPER K3=  .34452E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .177607E 03 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE           =  .610100E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE      = -.652977E 00 M/SEC
```

Case 2

```
** INPUT **
FREQUENCY=  140.0000 MHZ, LATITUDE=     .00000 DEG, LONGITUDE OF STATION= 355.00000 DEG
ELEVATION=  60.000000 DEG,  AZIMUTH= 90.000000 DEG,  HEIGHT OF SATELLITE=      500.0 KM,  ELEVATION RATE= -.11760290E-01 RAD/SEC
YEAR=68, MONTH= 8, DAY=15,  J.TIME= 6.0000000 HRS,                                         ALTITUDE RATE=  .40000000E 03 M/SEC

** OUTPUT **

HEIGHT AT MAXIMUM ELECTRON DENSITY              HM= 278.564 KM,  CRITICAL FREQUENCY FOF2=  5.645 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .825688E 17 E/(M*M),   ANGULAR  NTA=  .940649E 17 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA     YM= 143.564 KM,  OF TOPSIDE PARABOLA  YT= 143.564 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .78010E-05, MIDDLE K2=  .51093E-05, UPPER K3=  .32627E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .385616E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE           =  .193409E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE      = -.126028E 01 M/SEC
```

Case 5

```
** INPUT **

FREQUENCY=  140.0000 MHZ, LATITUDE=  75.00000 DEG, LONGITUDE OF STATION=  90.00000 DEG
ELEVATION=  90.000000 DEG,  AZIMUTH=360.000000 DEG,  HEIGHT OF SATELLITE=     2000.0 KM,  ELEVATION RATE=  .00000000E 00 RAD/SEC
YEAR=64, MONTH= 2, DAY=21,  J.TIME=10.0000000 HRS,                                         ALTITUDE RATE=  .20000000E 03 M/SEC

** OUTPUT **
HEIGHT AT MAXIMUM ELECTRON DENSITY              HM= 310.200 KM,  CRITICAL FREQUENCY FOF2=  2.355 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=  .156177E 17 E/(M*M),   ANGULAR  NTA=  .156177E 17 E/(M*M COLUMN)
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA     YM=  87.363 KM,  OF TOPSIDE PARABOLA  YT=  87.363 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=  .70521E-05, MIDDLE K2=  .46437E-05, UPPER K3=  .23461E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=  .434671E-02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE           =  .321120E 02 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE      = -.107691E-03 M/SEC
```

5.0 Preparation for Delivery

The completed CPCI (Computer Product Configuration Item) for the Bent Ionospheric Model consists of three parts which are packed and shipped separately: a magnetic tape, card decks, and a documentation manual. The tape is mailed first class or airmail and is marked with "Special Handling - Electro Magnetic Item." The card decks and manuals can be shipped third class. For storage of the magnetic tape and the card decks, a cool and dry place should be selected to insure that the good condition of the items is preserved. The following list described the delivered items in detail:

a) Magnetic tape containing the general ionospheric coefficients in either BCD or Binary code depending on the compatibility of the computers between which the transfer occurs.

b) Card decks:

1) Fortran card deck to copy the BCD tape with ionospheric coefficients to a Binary tape of the proper form. This deck is not needed if the required Binary tape is supplied in place of the BCD tape.

2) Fortran card deck for PROGRAM ION, standard version of the ionospheric program.

3) Data cards for testrun of PROGRAM ION.

4) Fortran card deck for PROGRAM TABGEN, preprocessor for the alternate version of the ionospheric program.

5) Data cards for testrun of PROGRAM TABGEN.

6) Fortran card deck for PROGRAM ION1, reduction program for the alternate version of the ionospheric program.

7) Data cards for testrun of PROGRAM ION1.

8) Additional data cards of solar input data from 1962 to 1973.

c) Manual: "Documentation and Description of the Bent Ionospheric Model." For the setup and checkout of the programs, Section 3.3.1 File Description and Section 4.1 Test Plan should be consulted.

6.0 Notes

Section 6.1 describes the development of the ionospheric model, the data base on which the analysis was founded and the justifications for the derivation of each step in the development. In Section 6.2 the accuracy and the limitations of the model are outlined; justifications of approximations used in the model are given along with estimates of the resulting errors.

6.1 Ionospheric Model Development

For several years scientists have investigated many different approaches to modeling the ionospheric profile on a theoretical basis. The names and types of these methods are well known and will not be discussed here, but it is obvious after all the years that a good theoretical ionospheric profile still does not exist.

The object of our past investigations was to come up with an ionospheric profile that could give much improved results for refraction corrections in satellite communications to ground or to another satellite than had been obtained with the Chapman and many other theoretical profiles. It would have been pointless for us to sit down and investigate another theoretical approach when so many more competent scientists are working on this problem. For this reason we decided that in this present time of computers, an empirical model taken from a vast data base may provide us with the profile we were looking for.

It was our intention to acquire ionospheric data of any kind that helped us build up a data base covering minimum to maximum of a solar cycle and providing information up to 1000km. The lower layers of the ionosphere were neglected in terms of their irregularities although their electron content was added into the larger F layer; this was done to simplify the approach and as the prime objective was to obtain refraction corrections through the ionosphere, or at least to a point above 150 km, such an elimination would not be very detrimental.

Data from bottomside ionospheric sounders was obtained over the year 1962 through 1969 covering 14 stations approximately along the American longitudes having geographic latitudes 76 degrees to -12 degrees or magnetic latitudes 85 degrees to 0 degrees. This data was in the form of hourly profiles of the ionosphere up to the f_oF2 peak. Topside soundings were acquired for the years 1962 to 1966 covering the magnetic latitude range 85 degrees to -75 degrees and providing electron density profiles from about 1,000 km down to a height just above maximum electron density. As the topside data was

not available near the solar maximum, electron density probe data was obtained from the Ariel 3 satellite over the period May 1967 to April 1968 from 70 degrees north to 70 degrees south geographic latitude and linked in real time to f_oF2 values obtained from 13 stations on the ground.

6.1.1 Ionospheric Profile

In order to analyse the vast amount of data that was obtained a number of assumptions had to be made. In the first case the topside sounding data did not geographically cover the entire globe and the bottomside data was only available for land masses and not over the oceans; however, as a local time effect is far more significant than a longitude effect, the data was analysed as a function of latitude and local time. Geographic longitude was, however, taken into account for the determination of maximum electron density by using the ITS coefficients for f_oF2 which are a function of latitude, longitude, time and solar activity. Secondly a theoretical profile was determined to which the data would fit. This profile which is used in the evaluation discussed later, is shown in Figure 2 and is the result of earlier work by Kazantsev (Reference 7), and unpublished work of Bent (1967) while at the Radio and Space Research Station in England and requires the knowledge of the parameters k_1, k_2, k_3, y_1, y_2, f_oF2, and h_s. The equation of the upper topside is exponential, namely,

$$N = N_0 e^{-k h} ,$$

the lower ionosphere is a bi-parabola,

$$N = N_s \left(1 - \frac{b_2^2}{y_2^2}\right)^2 ,$$

and the top and bottomside are fit together with a parabola,

$$N = N_s \left(1 - \frac{b_1^2}{y_1^2}\right) ,$$

where,

N	is the electron density
N_m	is the maximum value of electron density
N_o	is the maximum electron density for each exponential layer

a and b are vertical distances

y_m	is the half thickness of the lower layer
y_t	is the half thickness of the upper parabolic layer
k	is the decay constant for an exponential profile.

The upper parabola extends from the height of the maximum electron density up to the point where the slope of the parabola matches the slope of the exponential layer. The data investigated included over 50,000 topside soundings, 6,000 satellite electron density and related f_oF2 measurements, and over 400,000 bottomside soundings.

6.1.2 Topside Ionosphere

The initial approach was to take the topside soundings and break them down into zones 5 degrees of latitude by 40 minutes of local time eliminating data in the same zones that have similar times and profiles, and therefore are duplicated. This resulted in over 1,200 different areas in the northern and southern hemisphere with a reasonably constant density of data in each area. By these means it was possible to investigate the decay constant k in the exponential topside profile as a function of local time, latitude, solar flux, sunspot number and season. One of the major concerns was whether the decay constant k would be uniform for each sounding over the range 1,000 km to the minimum height, and investigations showed that such an exponential profile does not exist. The layer was, therefore, divided into three equal height sections from 1,000 km to the minimum recorded height and the exponent k computed for the center point in each section. Figure 2 shows such a division where the values under investigation are the decay constants k_1, k_2, k_3. In most cases the topside soundings do not reach the height

of maximum electron density and therefore the gradient at this lower point was mathematically equated to the point where the gradient of the 'nose' parabola was the same. Extensive analysis of the acquired data showed these gradients to be similar, on average, at a height $y_m/4$ above the maximum electron density. At this point the value of f_kF2, which defines the lowest point of the topside sounding, is 0.93 f_oF2. (N_m in Figure 2 is the equivalent electron density to the frequency f_kF2).

For an initial test the decay constants k for each of the three layers, upper, middle, and lower topside were plotted as a function of magnetic latitude and f_kF2. Values from the northern and southern hemispheres were treated independently at first, but the analysis showed that there was excellent correlation between the two. Figure 3 shows the relationship between the three decay constants k and magnetic latitude for all local times, solar activity, and season. The equatorial anomaly and a 40 degree trough show in the lower topside layer. The 65 degree trough is not as evident as it is when the same analysis is done for various local times which suggests the physical variances of these anomalies should be investigated in more detail.

It was found that correlations in k for specific f_kF2 did not bear any further local time correlation, but bore a significant variation with solar activity and magnetic latitude. However, the correlation with solar flux was considerably better than that with sunspot number, even allowing for the delay in the effect reaching the ionosphere, so all further correlations were with the Ottowa 10.7 cm solar flux. All these correlations were then plotted in graphical form to enable final interpolation.

Unfortunately the Alouette data did not cover the period at the peak of the solar cycle, but the Director of the U.K. Radio & Space Research Station made available electron density data from the Ariel 3 satellite to cover this period. The data had already been reduced thoroughly and the satellite electron density at about 550 km was provided with the sub-satellite f_oF2 value obtained from 13 stations around the world. If the satellite was not directly over an

ionosonde at the time of observation, the f_oF2 values from two or three transmitters in the general area had been interpolated in time and position to give the sub-satellite value. These interpolations had been carried out taking care to modify the values for uneven ionospheric gradients. Data that was in doubt was eliminated. While these values did not give the three exponential decay constants at each point, it was found that for similar conditions of solar flux and position, the Ariel 3 data fit very closely to the profiles deduced from Alouette 1. The profile equations developed for the lower solar activity period related to the topside sounders could, therefore, be extended to the larger solar flux values and still be in good agreement with the Ariel 3 data. Typical results from this analysis are shown in the graphs of Figure 4. The original data curves were less regular, and since the variations were mainly caused by the relatively low data density in each group after division of the large data base, the data was smoothed by the fitting of straight lines. In order to interpret these graphs and obtain a profile, we need the value of f_oF2 and the magnetic latitude position. These values will indicate which graph relates the 10.7 cm flux to the decay constants k for the upper, middle, and lower portions of the topside ionosphere. Figure 4, therefore, shows the basis of obtaining the 3 independent slopes of the topside ionosphere as a function of f_oF2, latitude, and solar flux.

A further correlation to investigate the seasonal effects on k was carried out with some 15,000 totally different Alouette soundings and fluctuations in the k values of $\pm$ 15% were noted from the average spring and autumn values. The seasonal variation is monitored by observing the change in the daily maximum solar zenith angle from the equinoctial mid-day value. Figure 5 shows the seasonal fluctuation in k for each of the three layers in the topside profile. There is considerable evidence that this seasonal relationship has an added local time factor and this point will shortly be under investigation.

Examination of the upper part of the 'nose' of the N-h profile is difficult because topside sounding information rarely gives any values in this region.

Evidence from many leading scientists also implies that the topside profiles have about a +4% error in the effective distance from the sounding satellite indicating the obtained topside profiles are too low near the peak. This evidence is based on comparisons with two-frequency data, backscatter results, Faraday rotation and overlap tests, etc. Preliminary results in this empirical model showed that a parabola in this region gave the better comparison with integrated total electron content when compared with two-frequency and Faraday rotation data. A simple parabola having a half thickness y_t was fitted between the bi-parabola and the exponential layer. Upon initial test y_t was set equal to the half thickness of the bi-parabola y_m for f_oF2 values below 10.5 MHz, and y_t increases with f_oF2 values rising above 10.5 MHz. Further investigations of this problem are planned in future work.

The final step in predicting the shape of the ionosphere is arranging for the gradient in the upper parabolic layer to be the same as the gradient in the lowest part of the topside exponential layer. This is the case at a distance $d = 1/k\,[(1+y_t^2 k^2)^{\frac{1}{2}} - 1]$ above the height of the maximum electron density.

6.1.3 Bottomside Ionosphere

Modeling the bottomside ionospheric profile was a somewhat easier task because for each profile the value of f_oF2 was known and the electron density versus height profile from h_{min} to h_{max} was also known. Once more the geographic effect of longitude was eliminated and replaced with the more simple local time correlation. From Figure 2 we see that the equation of the lower layer is a parabola squared or a bi-parabola. This was found in general to fit the real profile somewhat better than a simple parabola. The unknown in this equation is the half thickness of the layer y_m and in the reduction of the data the y_m value was treated in a similar way to a topside k value.

The irregularities in the ionosonde data due to the lower layers of the ionosphere were smoothed out because the prime objective of the work was to simplify the model, but keep the total content as accurate as possible. The

sounding data was therefore integrated up to the peak electron density (N_s) and forced to fit the bi-parabolic equation along with the value of N_s obtained from the sounding. In each instance the value of y_s was computed ready for further correlation.

A number of real profiles from various stations at different local times were compared with the computed profile and excellent agreement found. A further 12,000 soundings from all 14 stations were analyzed and the computed value of y_s compared to the actual measured value. These results are shown in Figure 6 along with the RMS errors. The two tests indicate that the bi-parabolic profile is, on average, in close agreement to the real profile. Investigations, similar to those carried out for the topside decay constants, correlated y_s with solar flux f_oF2, local time and season. Surprisingly, no direct correlation was found between y_s and solar flux, but a definite correlation existed in local time and also in the solar zenith angle at local noon which represents the season.

Figure 7 indicates how y_s can be determined from local time and f_oF2, and Figure 8 shows the seasonal update as a function of local time for the sunrise, sunset, night and daytime period. In the cases where f_oF2 was larger than 10 MHz the local time curve fluctuated very little from the 10 MHz curve. All of the curves displayed have not been hand smoothed; due to the large data base the average of all values taken every hour fit precisely on the lines shown.

The remaining unknowns which are needed to compute the profile are f_oF2 and the height of that value; by far the most important of these being the value of f_oF2.

6.1.4 Predicting f_oF2

Severe horizontal gradients in f_oF2 exist within the ionosphere as can be seen by examining Figure 9. In fact even if the value of f_oF2 is known directly above a station, it can change considerably over the whole visible ionosphere from that site. Figure 9 is a predicted status of f_oF2 over the world at 6.0 am during August 1968 and two types of severe gradients are immediately noticeable, one due to sunrise causes rapid changes in f_oF2 in an east to west direction and the other situated around the equatorial anomaly occurs primarily during the afternoon and early evening and causes severe gradients in the north to south direction. Two hypothetical stations, A and B, are marked on Figure 9 along with the ionosphere 'visible' from those sites. In case A the value of f_oF2 changes from 11.5 MHz directly overhead to 5 MHz on the southern horizon. This change must be squared when converting to electron content hence a difference of a factor of over 5 in the vertical content arises before correcting for elevation angle effects. Similar gradients exist over half the earth's surface at some time of the day and it is therefore imperative to model these gradients in any ionospheric model.

For many years NOAA (formerly CRPL and ITSA) have been engaged in the development of numerical methods and computer programs for mapping and predicting characteristics of the ionosphere used in telecommunications. The most advanced method for producing an f_oF2 model undoubtedly comes from their work. Jones, Graham & Leftin (Reference 5) describe their techniques on how a monthly median of the F2 layer critical frequency (f_oF2) was developed from an extremely large worldwide data base. In fact the gradient map shown in Figure 9 is a result of this work. We have already shown that it is important to include the horizontal gradients of f_oF2 in any analysis and the work by Jones et al is undoubtedly the only satisfactory approach to this problem.

The document by Jones et al describing this work includes a Fortran program which, with monthly coefficients obtainable from NOAA, enables the monthly median value of f_oF2 to be computed above any point in the world at

any time. This program was primarily written to accept monthly coefficients using an average sunspot number, but more recent work by Jones & Obitts (Reference 6) has described a more generalized set of coefficients which provides annual continuity and uses more extensive analysis. These generalized coefficients can be obtained from the Ionospheric Prediction Services, NOAA, Boulder, for a sunspot number or a solar flux approach. The value of a monthly median f_oF2 can be computed on a worldwide basis centralized around the specific day in question rather than the 15th of the month; it can also be based on a 12-month running average of solar flux or sunspot number. Private communication with Mrs. Leftin at NOAA indicates that the solar flux approach is likely to provide more accurate values of f_oF2 than the use of the sunspot number.

For the ionospheric profile under discussion, it was decided to use the generalized f_oF2 coefficients from NOAA incorporating solar flux thereby eliminating any need to purchase monthly data from them. The program was made self-contained and enabled a monthly median f_oF2 to be produced above any surface position for any time of day or season and any twelve month running average of solar flux.

The question now arises as to how good these monthly median values are and how much error is introduced by day to day fluctuations. Many daily soundings were analyzed and the monthly median value computed; these were compared with the monthly median predicted values and the actual day to day fluctuations. Some typical results are shown in Figure 10. It is seen that the monthly median predicted values are indeed very close to the actual measured value, but the day to day fluctuations can be as large as $\pm 75\%$. A technique therefore had to be derived to bring the computed monthly median value closer to the actual value.

It would be pointless to use the daily value of solar flux in the generalized coefficient set which had been built up using a twelve month running average, but it was thought possible that there may be a relation between the difference in f_oF2 from monthly median to daily value and the difference in the 12-month running average of solar flux to the daily value.

Approximately 6,000 real values of f_oF2 from 13 stations widely spread in latitude, longitude, and solar cycle were compared with the predicted values using the NOAA solar flux method. A very surprising result emerged and can be explained by referring to Figure 11. Eliminating the data from stations close to the magnetic poles which did not quite follow the trend of the other stations a comparison between the difference in daily and 12-month flux value and the percentage difference of computed and measured f_oF2 showed all stations having a very similar bias. Figure 11 shows this comparison where the stations having similar latitude were averaged quoting their mean magnetic latitude. The fact that the lines did not pass through the zero points in the graph undoubtedly indicates an erroneous bias in the NOAA predictions, but results help one to update substantially the monthly median f_oF2 value on a daily basis. Further comparisons were carried out with two years of hourly f_oF2 values obtained near solar maximum from Hawaii and the results fit perfectly in the latitude position expected in Figure 11. By these means it is possible to come somewhat nearer the actual daily value of f_oF2. Further accuracy can be derived by update from stations within the general area if this is available and the investigation of this approach will now be explained.

In order to investigate the size of an area from which ionospheric values would show similar deviations from normal, many comparisons of three or more stations were investigated for random dates. It is well known that magnetic disturbances can effect the ionosphere above one station in one direction and a nearby station in an opposite direction. For this reason investigations of disturbances were not carried out near to the magnetic poles. Over 100 groups of stations from various continents and having similar longitudes were compared in similar ways. Figure 12 is a typical result of such a test and shows f_oF2 disturbances being recorded simultaneously at sites 1,000km apart. The percentage error in the predicted f_oF2 value when compared to the real value was noted to be similar in 90% of the cases where stations were within 2,000km of one another in a longitudinal direction and investigations over the 'quiet' North American continent show improvement

in 9 out of 10 cases when f_oF2 was updated with information from across the continent; or 3,000 to 4,000km. However, in general, the update procedure is restricted to information from within 2,000km of the evaluating station.

6.1.5 Predicting the Height of the Maximum Layer

In order to predict the real height of f_oF2 the M(3000)F2 predictions from NOAA were used. To explain the terminology:

$$M(3000)F2 = M\ FACTOR = MUF(3000)F2 / f_oF2,$$

where MUF(3000)F2 is the maximum usable frequency to propagate by reflection from the F2 layer a distance of 3,000km. The M(3000)F2 predictions can be calculated on a monthly basis from a generalized set issued by NOAA and provide the monthly median value as a function of sunspot number.

Knowledge of this factor along with the f_oF2 value enables the height of the layer to be calculated using the equations of Appleton & Beynon (Reference 1). If M is the M(3000)F2 factor and one assumes that y_s divided by the height of the bottom edge of the lower layer is greater than 0.4, then it is possible to derive the following polynomial,

$$h_s = 1346.92 - 526.40M + 59.825M^2,$$

where h_s is the required height.

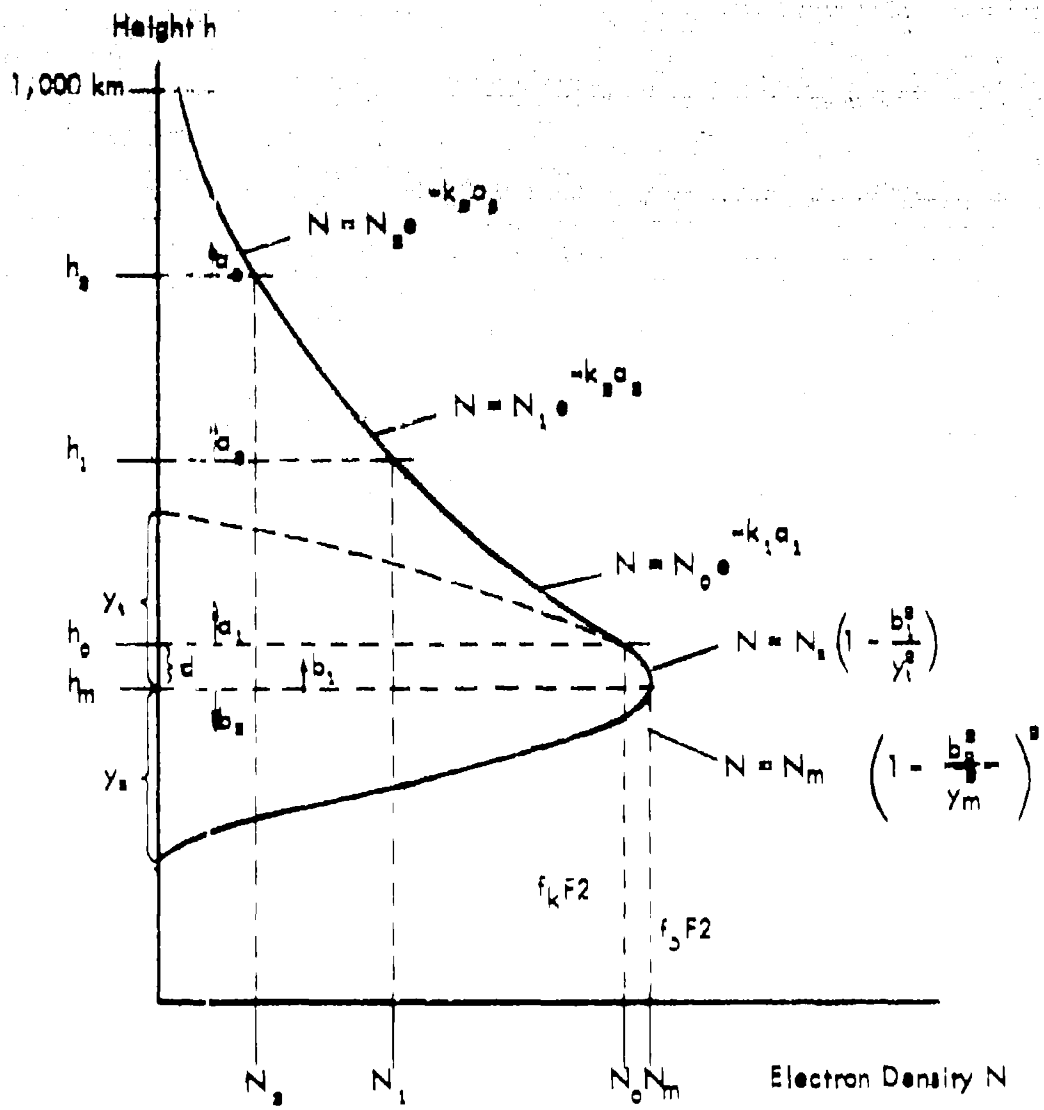


Fig. 2 The Exponential Parabolic & Bi-parabolic Profile

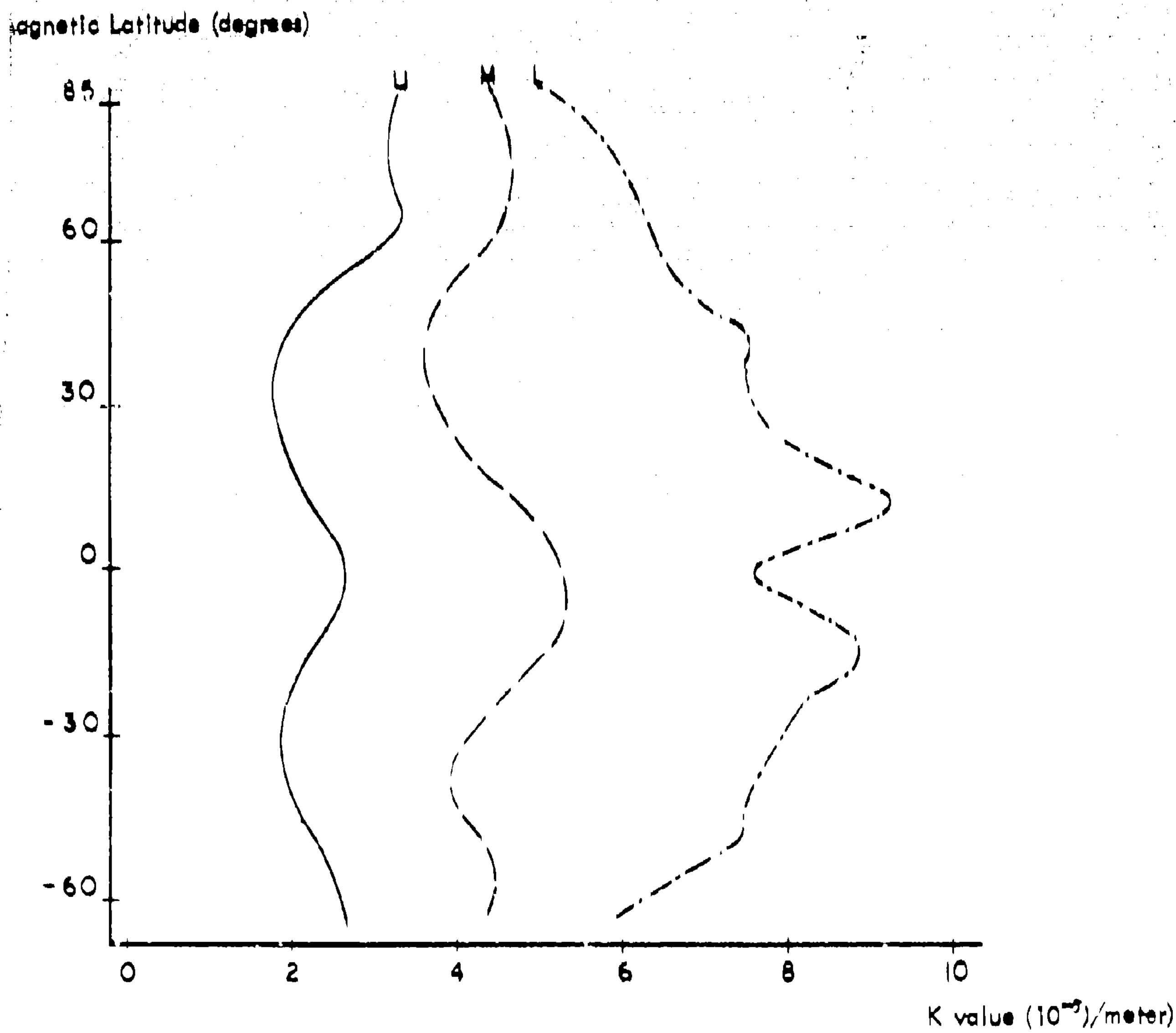


Fig. 3 The mean fluctuation of the decay constant k with magnetic latitude for the upper (U), middle (M) and lower (L) portions of the topside ionosphere.

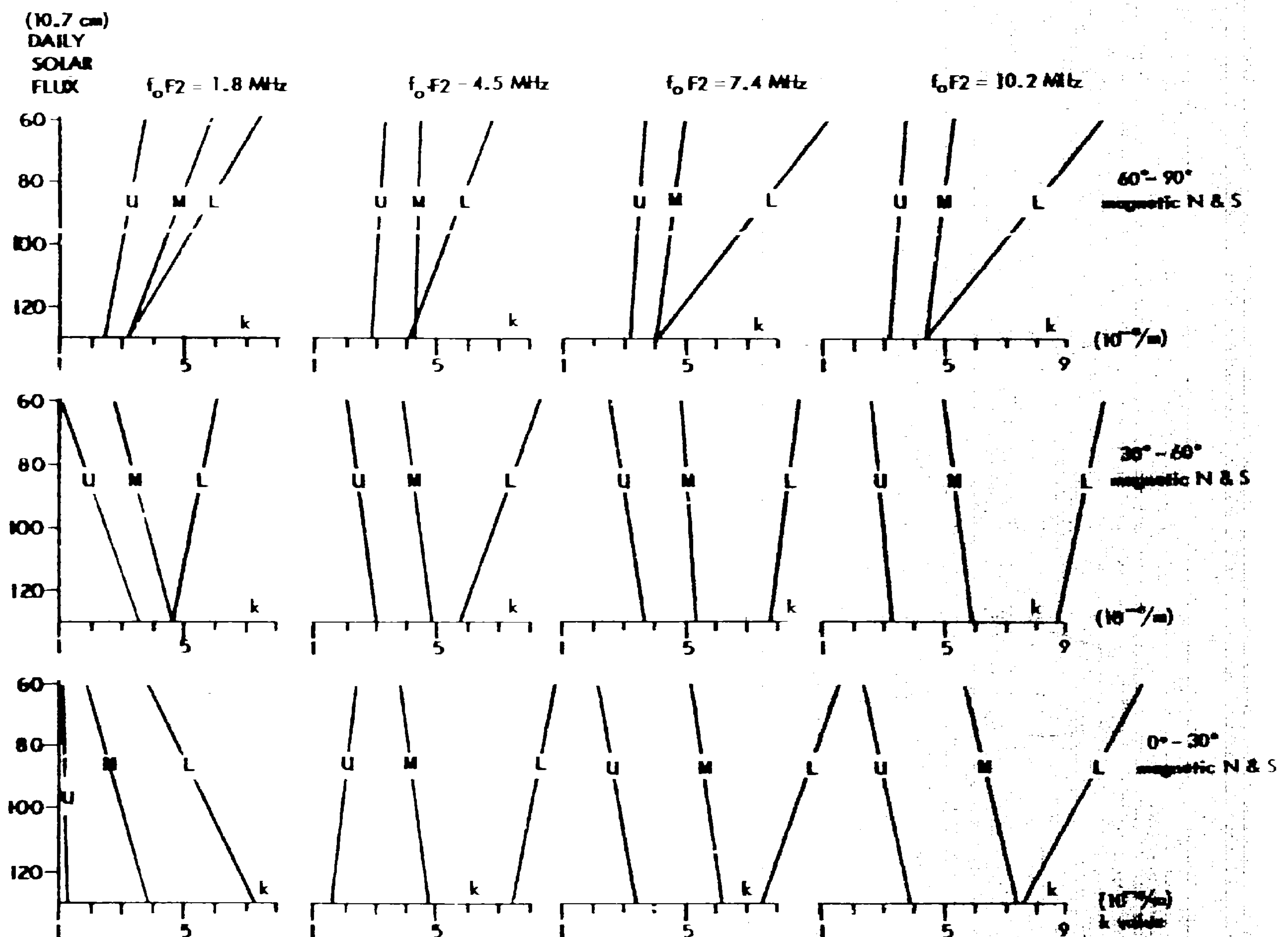


Fig. 4 Variation of k for the upper (U), middle (M) and lower (L) topside profile due to solar flux, f_oF2 and magnetic latitude.

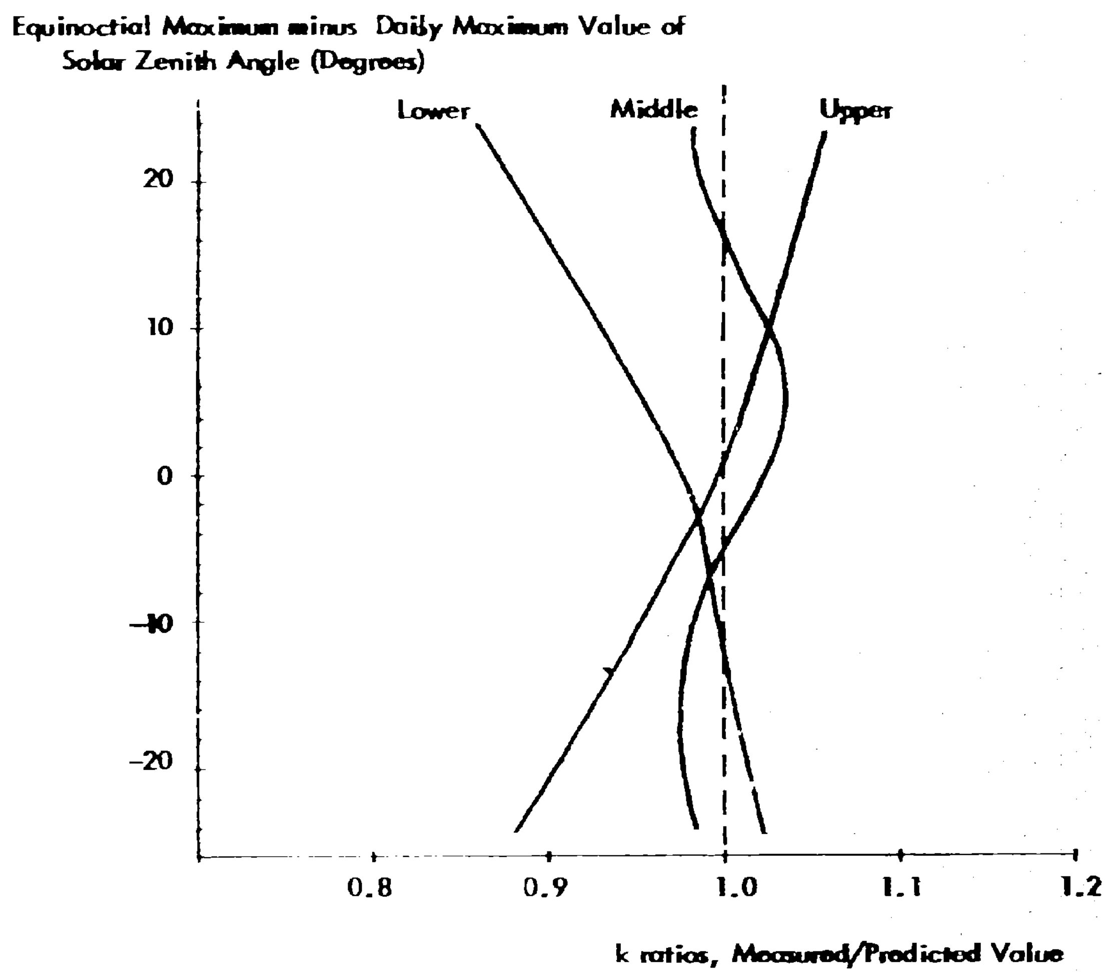


Fig. 5 The seasonal variation in the predicted k values

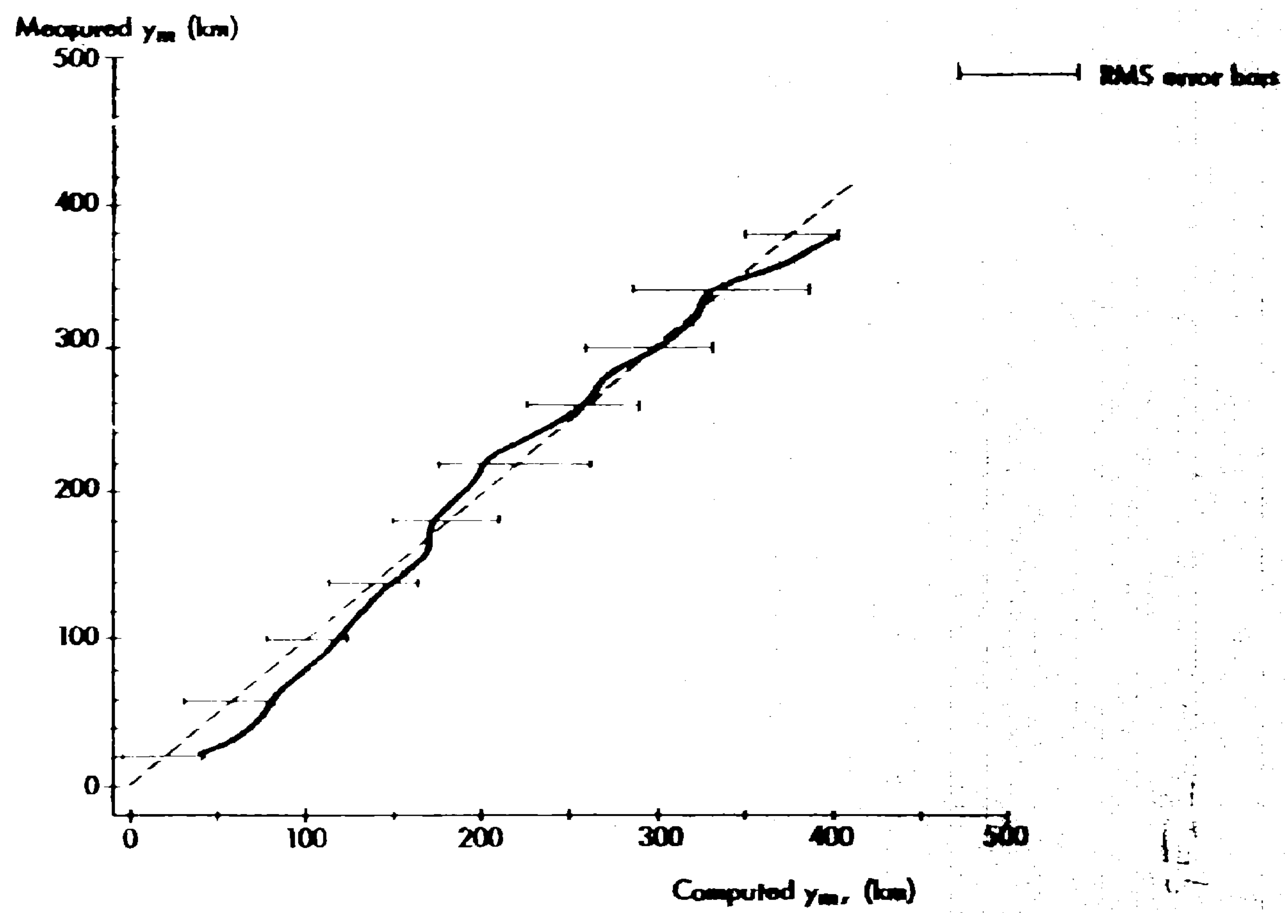


Fig. 6 The comparison of measured and predicted y_m for 12,000 profiles showing RMS error bars.

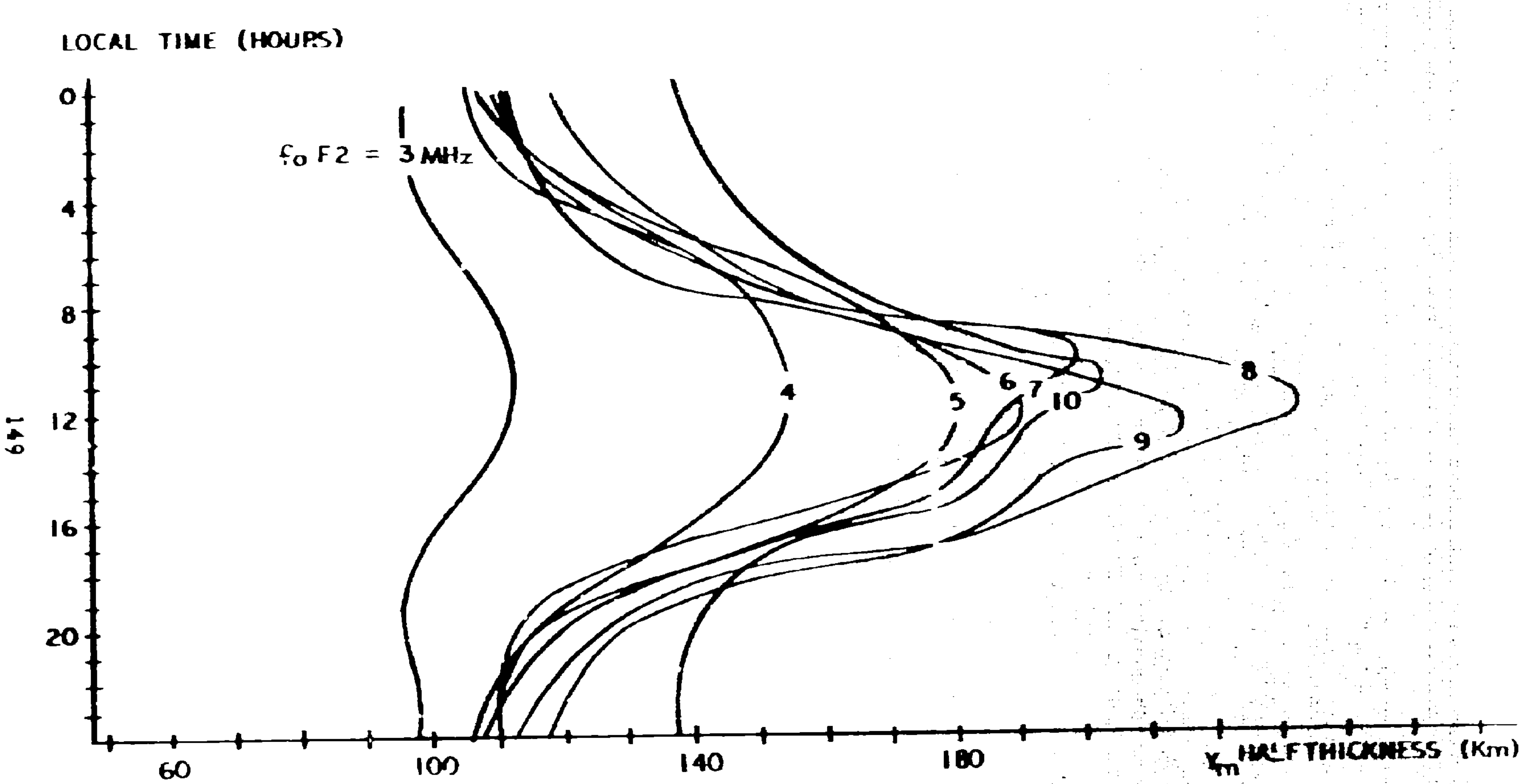


Fig. 7 Variation of y_m as a function of f_oF2 and local time.

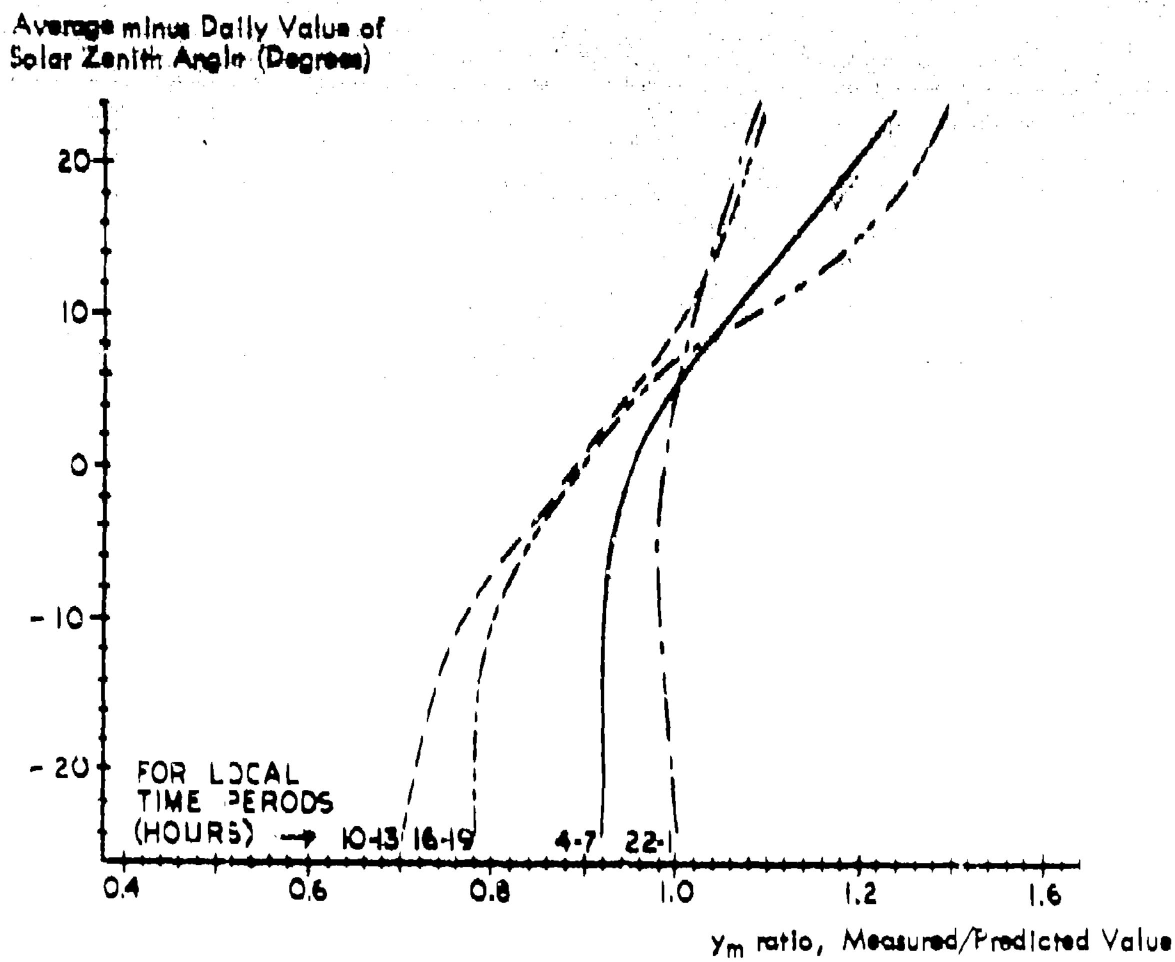


Fig. 8 The seasonal variation of predicted y_m as a function of local time.

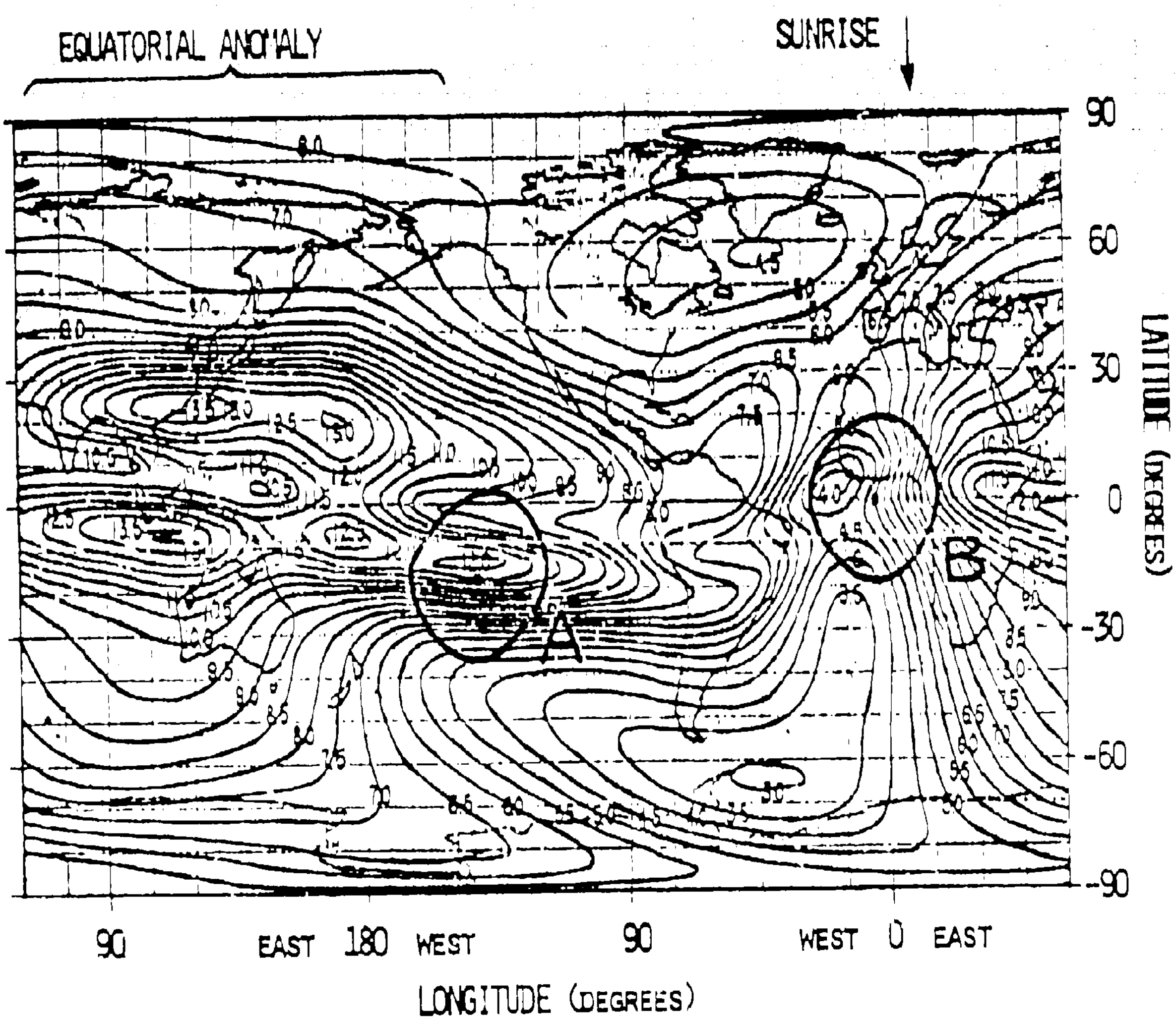


Fig. 9 The predicted global status of a monthly median $f_x F2$ at 6.0 a.m. UT August 1968 showing areas of visibility for two hypothetical ground stations.

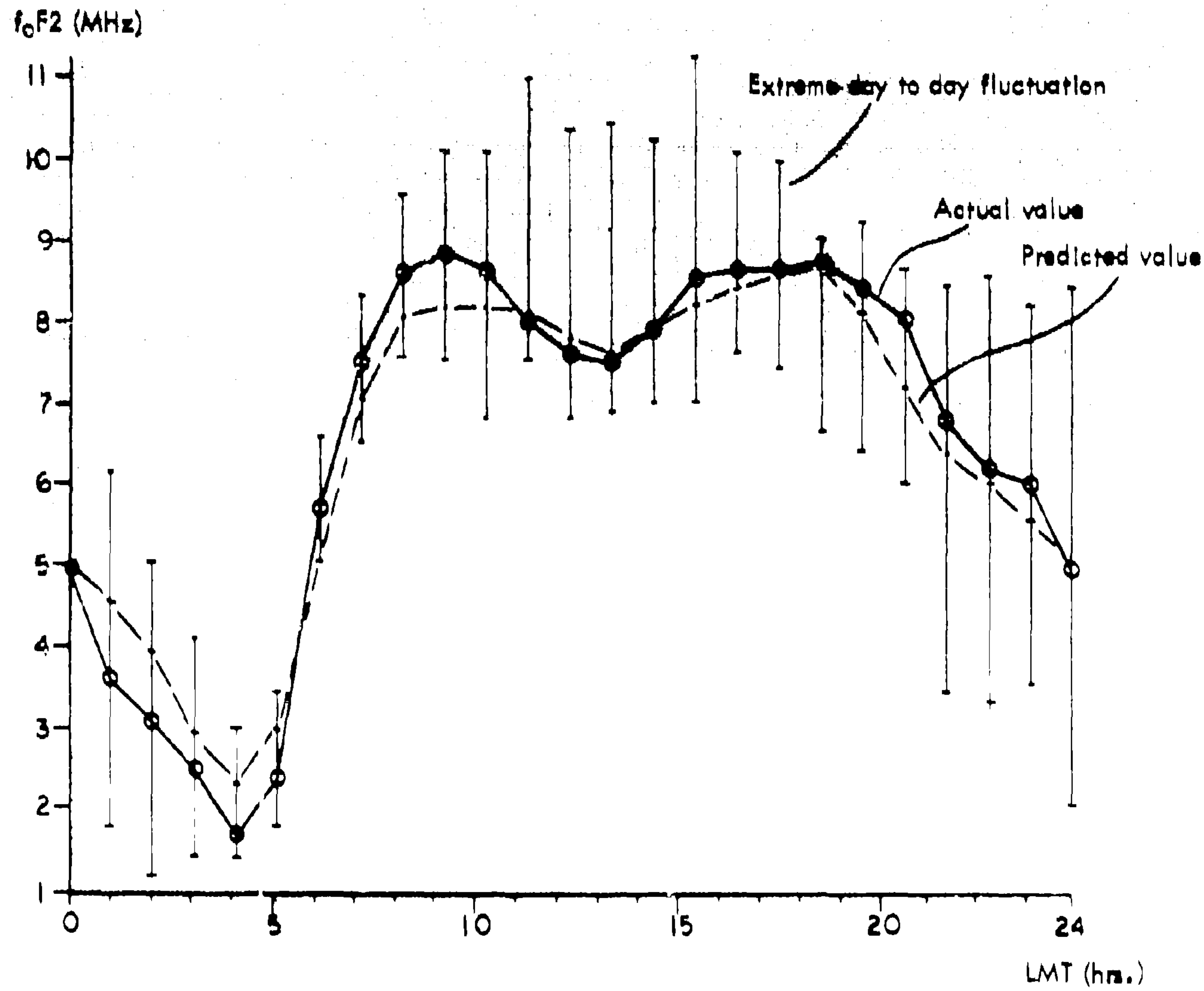


Fig. 10 The predicted and actual monthly median values of f_oF2 for Ibadan June 1962 showing the extreme day to day fluctuations.

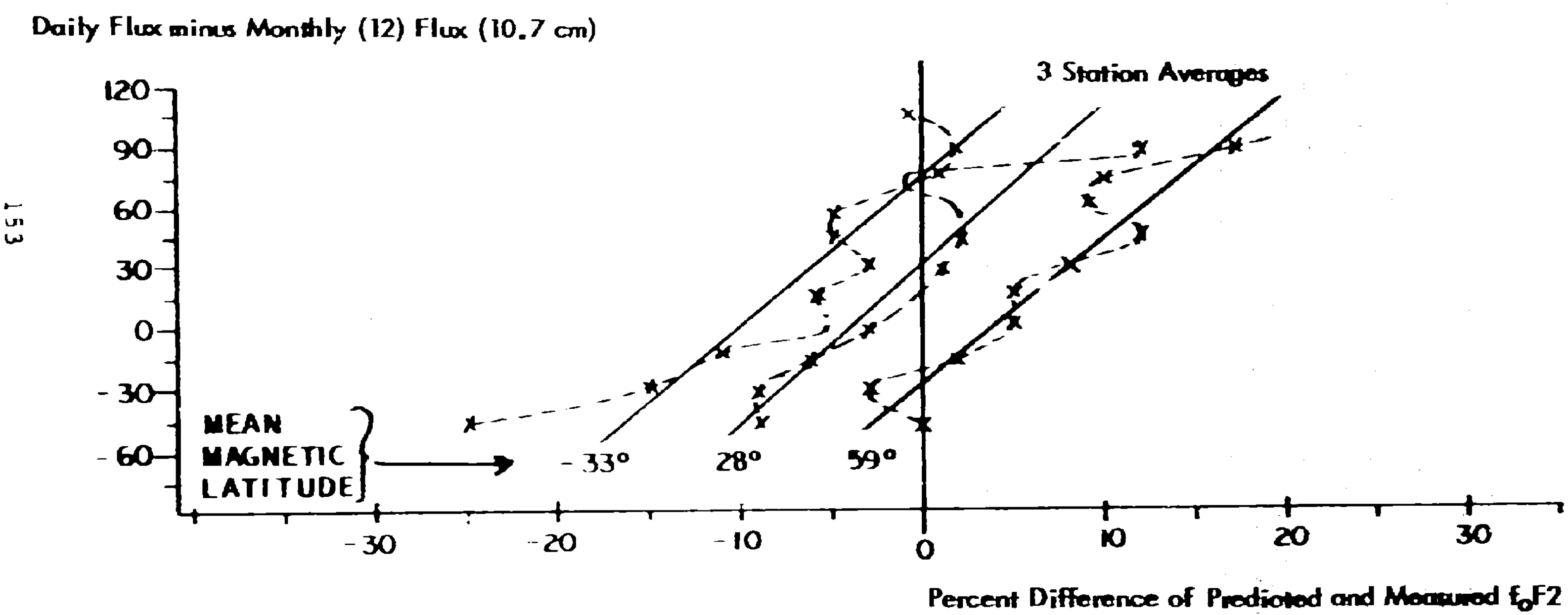


Fig. 11 An error in the NOAA f_oF2 predictions as a function of magnetic latitude and daily solar flux minus the 12 month running average.

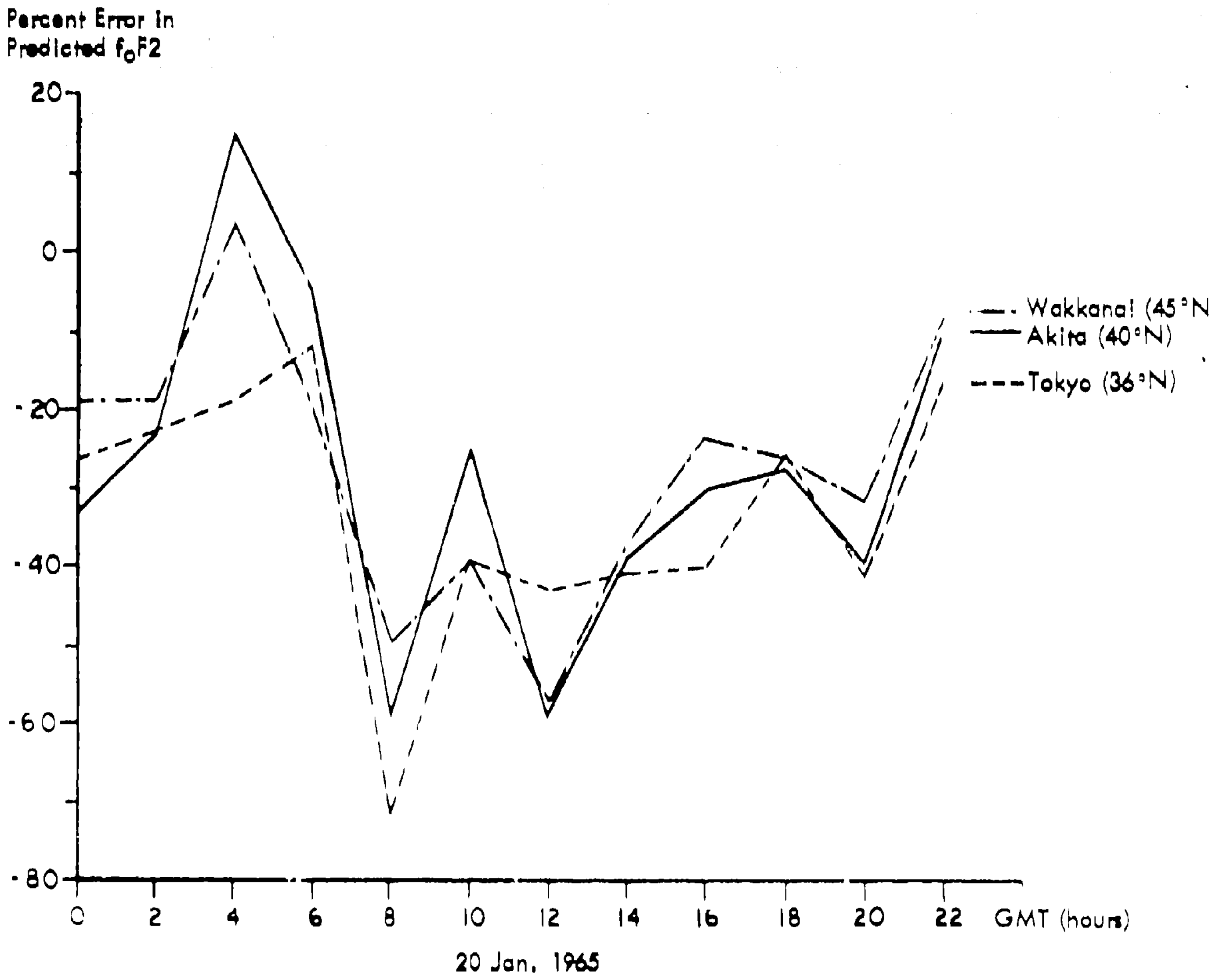


Fig. 12 Deviations in f_oF2 evident over a distance of 1,000 km

6.2 Model Accuracy and Limitations

As a means of testing the accuracy of the model, an intense comparison with Faraday rotation data has been performed as well as tests with two frequency data, actual ionospheric profiles, and use in orbit determination programs.

Remarkable improvements have been noticed in precise orbit determination systems and the model has reduced the number of iterations needed for the program to converge as well as the size of the residuals by up to a factor of four. Excellent results have been noted with orbit programs using elevation angle, range, and range rate systems.

The most extensive tests were carried out by comparing Faraday rotation data for seven stations from Hawaii to Puerto Rico to Alaska looking at the ATS1, ATS3, and SYNCOM3 satellites. In all, over 100 station months of continuous data were used during the years 1965 and 1967-1969 with data taken every hour. The integrated model data was compared with these actual results; unusual situations were also investigated. The results are shown in Figure 13 where the percentage of the ionosphere removed with the model is shown. In general, between 75 and 90% of the ionospheric effects are removed and these circumstances are for solar maximum conditions.

6.2.1 Basic Misconceptions in Ionospheric Modeling

During the course of developing this ionospheric model thorough investigations were carried out on a number of other ionospheric models as a means to finding their basic inaccuracies. The limitations and inaccuracies were then considered in the final development of the Bent Ionospheric Model.

Among the basic simplifications in the models leading to inaccuracies, were formulae related to a flat earth and ionosphere as well as little consideration for the height of the ionosphere. Each of these approaches causes f_0F2 to be evaluated at an incorrect position, consequently produces an error in f_0F2 which propagates into electron content and the refraction corrections, and in addition large errors in elevation angle correction can result from the incorrect geometric conditions.

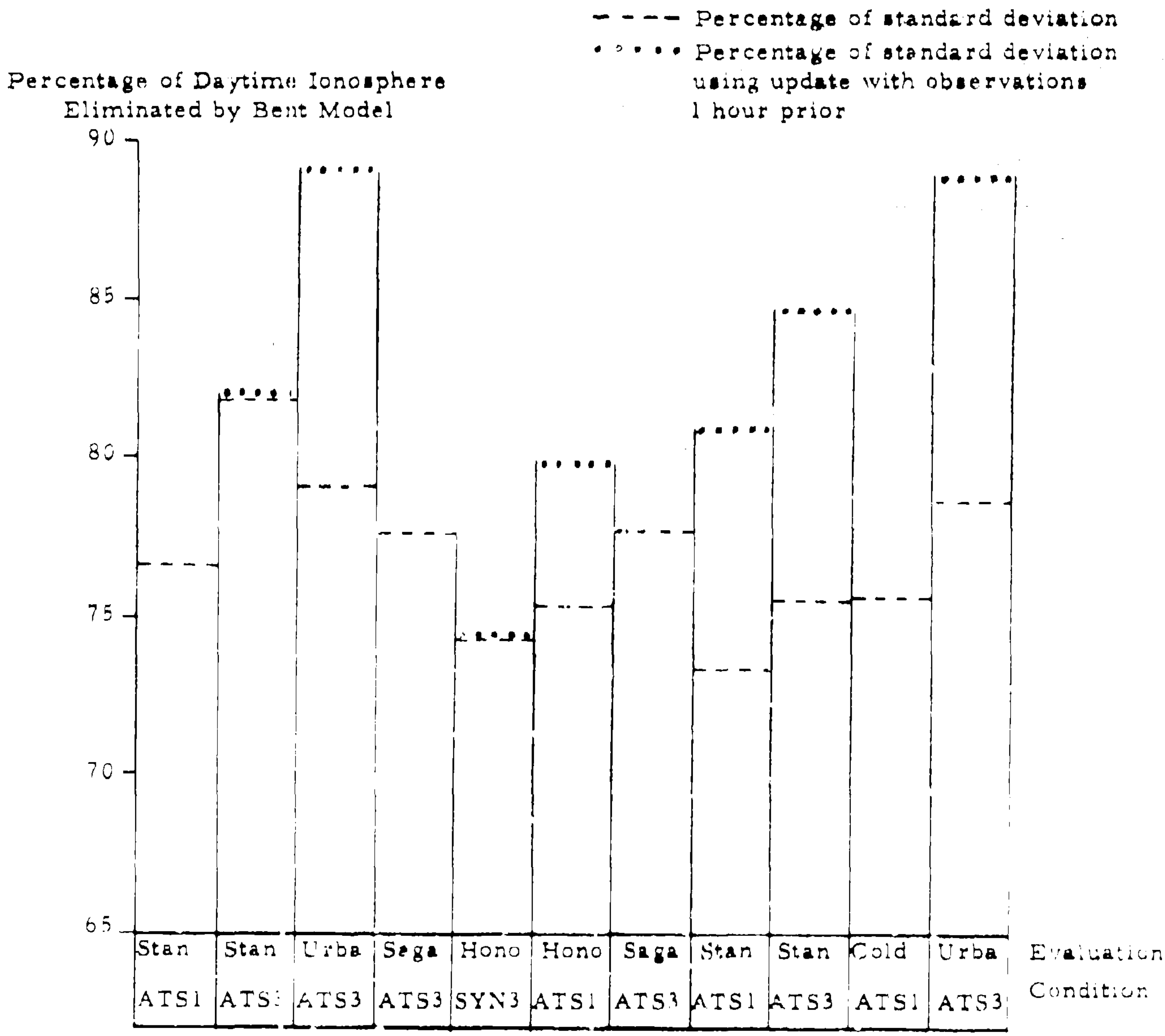


Figure 13 Percentage of Daytime Ionosphere Eliminated for Different Evaluation Conditions

The bad effect of a flat ionosphere on low elevation angle satellites is obvious, and serious problems also exist for satellites at large distances. Elevation angle corrections cannot be obtained for satellites at infinity, and errors of a factor of 2 in elevation angle still occur with satellites at 5000 km altitude. The height $h_s F2$ quite commonly changes by over 175 km during the course of a day at low latitudes. Ignoring the importance of the $h_s F2$ computation can give rise to an error of a factor of 2 in elevation angle correction, and at low elevations also to a difference of 3 degrees in earth central angle between the observer and the ionospheric point, which in turn can produce a change in $(f_o F2)^2$ of 20%.

6.2.2 Errors in Range Rate Computations

A problem can occur in computing range rate corrections through the ionosphere to a satellite. Many Doppler satellite tracking systems integrate cycle counts over a few seconds of time. The ionospheric corrections for such a technique are best obtained by range differencing the ionospheric corrections and dividing by the integration period; hence time, elevation and azimuth changes are incorporated. A typical ionospheric range rate correction can be significantly changed by the sixth digit in the ionospheric range correction; precautions have therefore to be taken to ensure that no irregularities occur in computing the two adjacent range corrections. Furthermore, the ionospheric height at the ray intersection point must be computed to 1km convergence in order to obtain a precise ionospheric latitude and longitude for $f_o F2$ computations. An error of over 1 km in $h_s F2$ will cause the $f_o F2$ value to be very slightly different and from this a change in the 5th or 6th digit in range can easily arise leading to very large errors in range rate. It is not claimed that $h_s F2$ has to be accurate to 1 km as this is an impossible prediction, but the values of $h_s F2$ should be consistent in their calculation to 1 km convergence.

The theoretical approach to range rate correction either by differentiating range or using the deviation angle of arrival at the satellite is in no way accurate.

The differentiating technique yields a correction to an instantaneous measurement which can vary greatly from the correction to Doppler range rate measured over a finite time interval, from a fraction of a second up to over a minute's time. In addition, the range rate correction is not only influenced by the change in the satellite position, but also by the changing ionosphere below the moving satellite, which has mostly been neglected in either approach. To explain this fact, consider the range correction ΔR as given by

$$\Delta R = \frac{K N_T}{\sin E} \qquad \text{where} \quad K = \frac{40.3}{f^2},$$

N_T is the integrated vertical content and E is the local elevation angle in the ionosphere. Differentiating ΔR while considering the case where the satellite passes directly overhead where no azimuth change is observed:

$$\Delta \dot{R} = -K N_T \frac{\cos E}{\sin^2 E}\,\dot{E} + \frac{K}{\sin E}\left(\frac{\delta N_T}{\delta E}\right)_{t = \text{constant}} \dot{E} + \frac{K}{\sin E}\left(\frac{\delta N_T}{\delta t}\right)_{E = \text{constant}}$$

In this equation the first term is in many cases the only one used, but it applies only to the instantaneous change in the satellite position. The other two terms are, however, often dominant. The second term is due to the positional change in the ionosphere and the last term represents the time variation of the ionosphere. For instance, with a high satellite moving east-west across the north-south ionospheric gradients at sunrise, the time variation is dominant as these gradients move towards the west with time. For a satellite moving north-south across the east-west ionospheric gradients near the equator, the time variation in the ionosphere is very small because the gradients change little in position while the ionosphere rotates with time. The second term which indicates positional change in the ionosphere is dominant for lower satellites where the ray path to the observer moves faster through the ionosphere. In cases where the satellite does not pass overhead the azimuth change must also be considered.

The Bent Ionospheric Model was developed for general use even at frequencies close to critical frequency and therefore all these basic misconceptions were eliminated as much as possible. The limitations still present in the system are now discussed in more detail.

6.2.3 Electron Density above 1000 km

The topside sounding data used to derive the data base for this model was taken from satellites at altitudes of about 1000 km and analysis showed that the ionosphere above h_mF2 is not truly exponential; in fact at times, large deviations from a perfect exponential layer exist. In the use of this model it is recommended that the decay constant from the uppermost exponential layer is the value that should be taken for all analysis between 1000 and 2000 km. At times, however, this value will be too large thereby giving a lower electron density than actually exists.

Some scientists have reported that 10 to 20% of the ionosphere lies above 1000 km, but there is not conclusive evidence to support this. Further studies are now underway using satellite topside sounding data at 3000 to 4000 km altitudes and the model will be improved accordingly.

6.2.4 The Uncertainty in the Profile just-above h_mF2

An uncertainty existed in defining a profile for the area just above h_mF2. Topside sounding data provided a profile to a short distance above h_mF2 and bottomside data provided accurate values to the height of h_mF2. In order to investigate this unknown region both parabolic and bi-parabolic profiles were incorporated into that part of the model and extensive tests carried out with total electron content data provided from Faraday rotation experiments. The model was used to predict total content to 2000 km where Faraday rotation probably ceases. The mean value of the residuals between Faraday computed electron content and model integrated electron content indicated the accuracy of the profile just above the peak. This region was found to have diurnal and seasonal dependency,but these characteristics have not yet been well enough defined to incorporate into the model. It was found, however, that a parabolic layer with half thickness a function of f_oF2 gave significantly improved results, but further work will be needed to define this region more accurately as a function of time and season.

6.2.5 Profile Inaccuracies in the Lower Layers

The model was developed primarily for use near to or above the height of the F2 layer of the ionosphere. For this reason, it was not necessary to model the E and F1 layers into the profile, but their density values were included in the total electron content below $h_s F2$. This total content was then used in the deviation of the lower layer bi-parabola. Care must be taken, therefore, in using the model if a profile of these lower layers is required, but if the requirements only involve total electron content or refraction corrections for values close to or above $f_o F2$, the model is quite accurate.

6.2.6 Maximum Limit on Solar Flux in the Derivation of the Topside Profile

It can be seen from Figure 4 that the topside exponential decay constants are a function of the 10.7 cm solar flux. The graphs shown in this figure indicate values only when the flux is below 130. This is primarily due to a lack of large amounts of data in the original data base for conditions of higher solar activity. It is not recommended to extrapolate the exponential decay constants beyond this value of flux as it is possible they may become negative giving an erroneous increase of electron density with height. It is suggested that the value of flux be kept at 130 even when measured values are larger.

6.2.7 Limitations in the Computation of $h_s F2$

The calculation of the height of the F2 layer is achieved by knowledge of M(3000)F2 and the use of the Appleton-Beynon equations (Reference 1). Basically a parabolic model is fit to the nose of the F2 layer and knowing the half thickness y_s, the lower limit h_0 of the bottom layer and the value of M(3000)F2, the simplified equations permit the calculation of h_s. The equations of Appleton and Beynon permit the construction of a family of curves

showing the variation of the M factor $MUF(3000)F2/f_oF2$ with distance for a range of values to the height of maximum electron density $h_s (=h_o + y_s)$ and for different values of the ratio y_s/h_o. Such a family of curves is shown in Figure 14. The equation used in this model for computing $h_s F2$ (see Section 6.1.5) is derived from these curves where, for a particular h_s, the M factor is constant over a wide range of y_s/h_o. This condition holds for $y_s/h_o \geq 0.4$. Examination of the curves shown in Figure 14 indicates that in general for accurate values of M(3000)F2, h_s will be accurate to $\pm$ 10 km. If this M factor is in error by $\pm$ 5%, we can have errors in h_s as large as $\pm$ 20 km. These errors will increase in the uncommon situations where y_s/h_o is smaller than 0.4.

6.2.8 Limitations in the Application of the Daily Solar Flux Update

Figure 11 shows the results of analyzing thousands of actual values of critical frequency against the predicted values, taking into consideration the daily and monthly solar flux. These values are typical for the following thirteen observing stations from which the data was reduced: Godhavn, Churchill, Boulder, White Sands, Hawaii, El Cerillo, Kenora, Paramaribo, Cocos Island, Buenos Aires, Hobart, Port Stanley, and Argentine Island. The only stations listed that are not on the North and South American chain are Hawaii, Cocos Island, and Hobart, but the results from these stations closely resemble the pattern set up by the American stations.

In using this update procedure outside the American chain one must, therefore, bear in mind that the pattern displayed in Figure 11 is not necessarily a worldwide pattern. However, the results from Hawaii, Cocos Island, and Hobart indicate that this update procedure can be used elsewhere with caution.

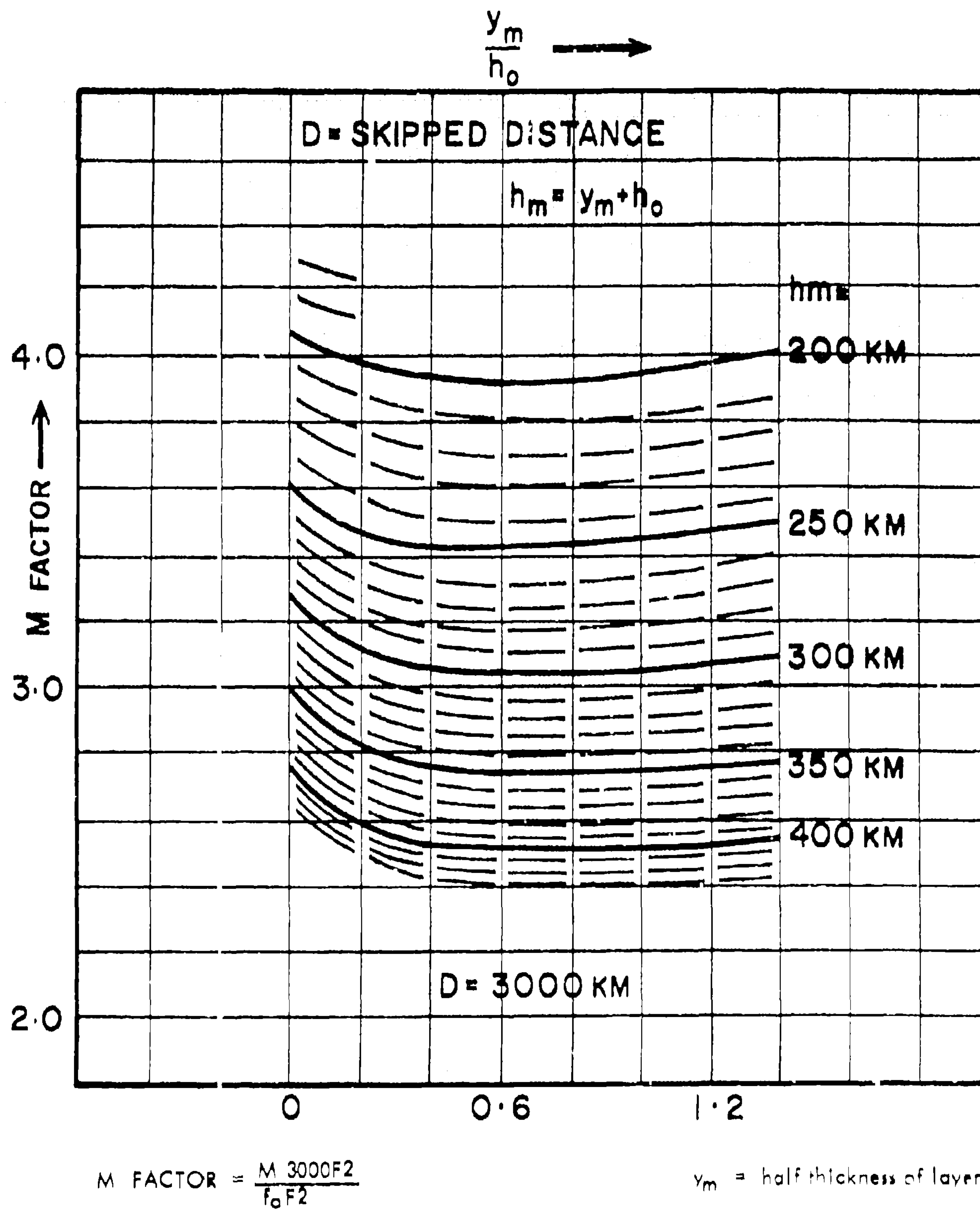


Figure 14. Family of Curves from the Appleton-Beynon Equation.

6.2.9 The Errors due to Neglecting Angular Refraction in the Computation of ΔR and $\Delta \dot{R}$

The computation of total electron content for determining the ionospheric range and range rate correction assumes the ray passes through the ionosphere undeviated. This assumption was made because the majority of the work for which the model was being developed was for VHF and S band frequencies. Should the actual path length of the ray be much different from the undeviated ray, as will be the case at lower frequencies, Maliphant (Reference 8) gives the following equation for true path length d and apparent path length d',

$$d = d' - \alpha R_e \cos E$$

where α is the angular separation of the true ray path above and below the ionosphere, R_e is the radius of the earth and E is the observed elevation angle at the earth's surface. Maliphant (Reference 8) also gives a formula for computing d in wavelengths.

6.2.10 Limitations in the Computation of Angular Refraction

In the computation of ionospheric elevation angle correction, we have used the technique of Maliphant (Reference 8). Anyone wishing to use this technique at frequencies close to critical frequency should read the above reference, in particular where the deviation factor $\left(\frac{f_oF2}{f} \sec \phi_s\right)$ is larger than 0.9. ϕ_s is the angle of incidence of the apparent direction of propagation measured from the vertical at the height of maximum electron density.

In the Maliphant formula the exact equation for ray deviation has been simplified by separating the functions that are sensitive to distribution changes, and then approximating these functions for a typical electron distribution. The resulting functions vary by only small amounts with changes in electron distribution of the earth's ionosphere so that the equation may be used for most of the values of the deviation factor. However, when the deviation factor is larger than 0.9, the deviation angle thus obtained should be used with

caution as the error may be quite large.

Ray trace comparison at VHF with the model described in this report have shown possible errors in elevation angle correction of only a few percent, and these occur only close to the horizon.

6.2.11 Additional Limitations to the Alternate Version of the Ionospheric Program due to Interpolation of the Preprocessed f_oF2-h_s Tables

Section 3.2.1.1 CPC No. 12 describes how the tables with values of f_oF2 and h_s are computed and stored for specific times at one hour intervals around sunrise and two hour intervals otherwise, and for the locations around the station defined by the 25 point grid pattern shown in Figure 1 of that section. f_oF2 and h_s for any specific condition are later extracted from the tables by interpolating in time and space. Interpolation over stable ionospheric zones such as North America provides quite accurate results, but problems can arise at sunrise and at places with lower magnetic latitudes.

A number of simulations were performed for situations where the ionospheric gradients were changing rapidly in time around sunrise and in position around the equatorial anomaly. The following errors were detected when comparing the results from the time and space interpolation with the actual model values. In general h_s was interpolated to only two percent error or better than 10 km. The interpolation in f_oF2, however, provided larger errors. At sunrise, the grid was computed at one hour intervals and the largest possible time interpolation over half an hour provided on the average an RMS error in $(f_oF2)^2$ of 8% with a maximum excursion to 16% for all values of f_oF2 larger than 6 MHz. But for critical frequencies smaller than 6 MHz, the percentage values can be quite a bit larger. Around the equatorial anomaly where the ionosphere changes faster with position than with time, the grid was computed every two hours, allowing for the largest time interpolation over one hour; again an RMS error of 8% in $(f_oF2)^2$ was noted and the maximum excursion was 19%.

10.0 Appendix I

The instruction listings in this section specify the exact configuration of the Bent Ionospheric Program ION and the alternate version TABGEN-ION1. The main programs and subroutines are listed in order of their CPC Numbers.

Requirements for version ION;

PROGRAM	ION,	CPC No. 1
SUBROUTINE	REFRAC,	CPC No. 2
SUBROUTINE	PLOTNH,	CPC No. 3
SUBROUTINE	PROFL1,	CPC No. 4
SUBROUTINE	PROFL2,	CPC No. 5
SUBROUTINE	BETA,	CPC No. 6
SUBROUTINE	SICOJT,	CPC No. 7
SUBROUTINE	DKSICO,	CPC No. 8
SUBROUTINE	MAGFIN,	CPC No. 9
SUBROUTINE	GK,	CPC No. 10
SUBROUTINE	DKGK,	CPC No. 11

Requirements for version TABGEN-ION1;

PROGRAM	TABGEN,	CPC No. 12	(subroutines of the above list required are SICOJT, DKSICO, MAGFIN, GK, DKGK)
PROGRAM	ION1,	CPC No. 13	
SUBROUTINE	REFRC1,	CPC No. 14	(subroutines of the above list required are PROFL2, BETA)

```
C
C     PROGRAM ION(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1)
C     COMPUTES IONOSPHERIC PROFILE PARAMETERS AND REFRACTION CORRECTIONS
C
C     CONTENT OF COMMON BLOCKS EXPLAINED IN SUBROUTINE REFRAC
      COMMON /EVAL/ FS,FLAT,FLON,FLEV,AZ,HS,EDOT,HDOT,TIME,FLXD,SIG,SIF,
     *IYR,MON,IDAY,IOPT,IDEL,IDRO,IUPDT,ITP
      COMMON /UPDT/ ULAT,ULON,ULEV,UZIM,UT,OBS,ITYP,NUPDT
      COMMON /CORR/ DRANG,DRATE,DELEV,FOF2,HM,YM,YT,XK,TOTN,TOTNA
C
      DIMENSION XK(3),ISEL(5)
      DIMENSION MEAS(5,3),ULAT(8),ULON(8),ULEV(8),UZIM(8),OBS(8),UT(8),
     *ITYP(8),FLX(31)
      DATA GD,C1000,C3600,DR,HR,P12/0.  ,1000.  ,3600.  ,.0174532925  ,
     *.2617993878  ,6.2831853072  /
      DATA LYRMO,IDRO,IOPT/0,0,1/
      DATA MEAS/4H    O,4HBSER,4HVED ,4HFOF2,4HMHZ ,4HOBS.,4HVERT,4H.CON,
     *4HTENT,4HE/M2,4HOBS.,4HANGL,4H.CON,4HTENT,4HE/M2/
      ITP=1
C
C     SET UPDATE FLAG AND OUTPUT SELECTIONS
      READ(5,1) ISEL
      READ(5,1) IUPDT,IDRDAV
    1 FORMAT(5I5)
      DO 16 I=1,3
      IF(ISEL(I).EQ.0) IOPT=2
   16 CONTINUE
      IF(ISEL(4).EQ.0) IOPT=3
      IF(ISEL(5).EQ.0) IOPT=4
      IF(IOPT.LT.3.AND.IDRDAV.EQ.1) IOPT=3
      IDEL=ISEL(3)
      IF(IUPDT.EQ.0) WRITE(6,2)
    2 FORMAT(1AH *** NO UPDATE ***)
   10 CONTINUE
C
C     READ AND PRINT EVALUATION CONDITION
      READ(5,3)FS,FLAT,FLON
    3 FORMAT(F10.4,2F10.5)
      IF(FS.LT.0.  ) GO TO 100
      READ(5,4)FLEV,AZ,HS,EDOT,HDOT
    4 FORMAT(2F10.6,F10.0,2E15.8)
      READ(5,5)IYR,MON,IDAY,TIME
    5 FORMAT(3I5,F10.7)
      WRITE(6,6)FS,FLAT,FLON,FLEV,AZ,HS,EDOT,IYR,MON,IDAY,TIME,HDOT
    6 FORMAT(1H1,11H** INPUT **//
     *                  11H FREQUENCY=,F10.4,15H MHZ, LATITUDE=,F10.5,
     *27H DEG, LONGITUDE OF STATION=,F10.5,4H DEG/11H ELEVATION=,F10.6,
     *15H DEG,  AZIMUTH=,F10.6,27H DEG,  HEIGHT OF SATELLITE=,F11.1,
     *21H KM,  ELEVATION RATE=,E15.8,8H RAD/SEC/6H YEAR=,I2,8H, MONTH=,
     *I2,6H, DAY=,I2,10H,  U.TIME=,F10.7,5H HRS,/39X,15H ALTITUDE RATE=,
     *E15.8,6H M/SEC)
C
```

```
C       CØNVERT UNITS
        FLAT=FLAT*DR
        FLØN=FLØN*DR
        ELEV=ELEV*DR
        AZ=AZ*DR
        HS=HS*0.1000
        TIME=TIME*HR
        IYRMØ=IYR*100+MØN
C
C       READ AND SELECT SØLAR DATA
        IF(IYRMØ.EQ.LYRMØ) GØ TØ 30
        READ(5,7)IYM1,(FLX(I),I=1,16),IYM2,(FLX(I),I=17,31),IYM3,SIS,SIF
      7 FØRMAT(I4,4X,16F4.1/I4,15F4.1/I4,2F5.1)
        IF(IYM1.EQ.IYM2.AND.IYM2.EQ.IYM3.AND.IYM3.EQ.IYRMØ) GØ TØ 20
        WRITE(6,8)IYR,MØN
      8 FØRMAT(//39H ***ERRØR IN SØLAR INPUT DATA FØR YEAR=,I2,11H AND MØN
       *TH=,I2)
        GØ TØ 100
     20 LYRMØ=IYRMØ
     30 FLXD=FLX(IDAY)
        WRITE(6,15)FLXD,SIF,SIS
     15 FØRMAT(12H DAILY FLUX=,F6.1,41H, 12-MØNTH RUNNING AVERAGE ØF SØLAR
       * FLUX=,F6.1,20H, ØF SUNSPØT NUMBER=,F6.1)
C
C       READ AND PRINT UPDATE DATA
        IF(IUPDT.EQ.0) GØ TØ 50
        READ(5,1)NUPDT
        IF(NUPDT.EQ.0) GØ TØ 50
        MUPDT=NUPDT-8
        IF(MUPDT.GT.0) NUPDT=8
        WRITE(6,9)
      9 FØRMAT(/13H UPDATE DATA=)
        DØ 40 I=1,NUPDT
        READ(5,11)ULAT(I),ULØN(I),ULEV(I),UZIM(I),UT(I),ØBS(I),ITYPE
     11 FØRMAT(2F10.5,2F10.6,F10.7,F15.8,I5)
        WRITE(6,12)I,ULAT(I),ULØN(I),ULEV(I),UZIM(I),UT(I),(MEAS(L,ITYPE),
       *L=1,4),ØBS(I),MEAS(5,ITYPE)
     12 FØRMAT(1X,I1,5H)LAT=,F10.5,7H, LØNG=,F10.5,7H, ELEV=,F10.6,7H, AZI
       *M=,F10.6,9H DEG, UT=,F10.7,6H HRS, ,4A4,1H=,E15.8,1X,A4)
C
C       CØNVERT UNITS ØF UPDATE DATA
        ULAT(I)=ULAT(I)*DR
        ULØN(I)=ULØN(I)*DR
        ULEV(I)=ULEV(I)*DR
        UZIM(I)=UZIM(I)*DR
        UT(I)=UT(I)*HR
     40 ITYP(I)=ITYPE
        IF(MUPDT.LE.0) GØ TØ 43
        DØ 41 J=1,MUPDT
     41 READ(5,11) SKIP
        WRITE(6,42)
     42 FØRMAT(31H REMAINING UPDATE DATA NØT USED)
     43 CONTINUE
```

```
C
C     CØMPUTE AND PRINT IØNØSPHERIC DATA
   50 CALL REFRAC
      IF(IYR.LT.0) GØ TØ 10
      XHM=HM/G1000
      WRITE(6,21) XHM,FØF2
   21 FØRMAT(//13H ** ØUTPUT **//35H HEIGHT AT MAXIMUM ELECTRØN DENSITY,
     *10X,3HHM=,F8.3,30H KM,   CRITICAL FREQUENCY FØF2=,F7.3,4H MHZ)
      IF(ISEL(1 .NE.0) GØ TØ 17
      XYM=YM/G1000
      XYT=YT/G1000
      WRITE(6,22)TØTN,TØTNA,XYM,XYT,XK
   22 FØRMAT(48H TØTAL INTEGRATED ELECTRØN CØNTENT, VERTICAL NT=,E13.6,
     *25H E/(M*M),     ANGULAR  NTA=,E13.6,15H E/(M*M CØLUMN)/
     *48H HALF THICKNESS ØF BØTTØMSIDE BIPARABØLA      YM=,F8.3,
     *30H KM,  ØF TØPSIDE PARABØLA  YT=,F8.3,3H KM/
     *58H DECAY CØNSTANTS FØR TØPSIDE EXPØNENTIAL LAYERS, LØWER K1=,
     *E12.5,12H, MIDDLE K2=,E12.5,11H, UPPER K3=,E12.5,4H 1/M)
   17 IF(ISEL(3 .NE.0) GØ TØ 18
      TELEV=DELEV*206265.  /DR
      WRITE(6,23)TELEV
   23 FØRMAT(54H IØNØSPHERIC REFRACTIØN CØRRECTIØN TØ ELEVATIØN ANGLE=,
     *E13.6,11H SEC ØF ARC)
   18 IF(ISEL(4 .EQ.0) WRITE(6,24) DRANG
   24 FØRMAT(43H IØNØSPHERIC REFRACTIØN CØRRECTIØN TØ RANGE,10X,1H=,
     *E13.6,2H M)
      IF(ISEL(5 .EQ.0) WRITE(6,25) DRATE
   25 FØRMAT(54H IØNØSPHERIC REFRACTIØN CØRRECTIØN TØ RANGE RATE      =,
     *E13.6,5H M/SEC)
      IF(ISEL(2 .EQ.0) CALL PLØTNH(FØF2,HM,YM,YT,XK)
      IF(IDRDAV.NE.1) GØ TØ 10
C
C     CØMPUTE RANGE RATE CØRR. FØR ØBSERVATIØN ØVER FINITE TIME
      DT=TIME
      READ(5,13  ELEV,AZ,HS,TIME
   13 FØRMAT(2F10.6,F10.0,F10.7)
      WRITE(6,14)ELEV,AZ,HS,TIME
   14 FØRMAT(//47H ** INPUT **  SECØND SATELLITE PØSITIØN USED FØR RANGE
     * DIFFERENCING/13X,11H ELEVATIØN=,F10.6,15H DEG,   AZIMUTH=,F10.6,
     *14H DEG,   HEIGHT=,F11.1,13H KM,    TIME=,F10.7,4H HRS)
      ELEV=ELEV/DR
      AZ=AZ*DR
      HS=HS*G1000
      TIME=TIME*HR
      DT=TIME-DT
      IF(DT.LT.0.) DT=H12+DT
      DT=DT*3600/HR
      DRANGS=DRANG
      IDRD=1
      CALL REFRAC
      IDRD=0
      DRDAV=-(DRANG-DRANGS)/DT
      WRITE(6,26)DT,DRDAV
```

```
 26 FØRMAT(13H ** ØUTPUT **/13X,51H RANGE RATE CØRRECTIØN FØR RANGE DI
   *FFERENCING ØVER ,F10.4,10H SECØNDS *,E14.6,6H M/SEC)
    GØ TØ 10
100 CØNTINUE
    STØP
    END
```

```
C
C          IØNØSPHERIC REFRACTIØN MØDEL
      SUBRØUTINE REFRAC
C
C   INPUT: CØMMØN /EVAL/, CØMMØN /UPDT/
C   ØUTPUT: CØMMØN /CØRR/
C
      CØMMØN /EVAL/ FS,FLAT,FLØN,ELEV,AZ,HS,EDØT,HDØT,TIME,FLXD,SIS,SIF,
     *IYR,MØN,IDAY,IØPT,IDEL,IØRD,IUPDT,ITP
C  FS    = TRANSMISSIØN FREQUENCY IN MHZ
C  FLAT  = STATIØN LATITUDE IN RADIANS ØF ARC
C  FLØN  = STATIØN LØNGITUDE IN RADIANS ØF ARC (PØSITIVE EAST,0 TØ 360 D)
C  ELEV  = ELEVATIØN ØF SATELLITE IN RADIANS ØF ARC
C  AZ    = AZIMUTH ØF SATELLITE IN RADIANS ØF ARC
C  HS    = HEIGHT ØF SATELLITE IN METERS
C  EDØT  = ELEVATIØN RATE IN RADIANS ØF ARC/SECØND
C  HDØT  = RATE ØF CHANGE IN HEIGHT ØF SATELLITE IN METERS/SECØND
C  TIME  = UNIVERSAL TIME IN RADIANS ØF ARC
C  FLXD  = DAILY SØLAR FLUX
C  SIS   = 12 MØNTH RUNNING AVERAGE ØF SUNSPØT NUMBER
C  SIF   = 12 MØNTH RUNNING AVERAGE ØF SØLAR FLUX
C  IYR   = YEAR (LAST 2 DIGITS ØNLY)
C  MØN   = MØNTH (=1 THRØUGH 12)
C  IDAY  = DAY (=1 THRØUGH 31)
C  IØPT  = ØUTPUT SELECTIØN FLAG, =1 CØMPUTE FØF2,HM,
C          =2 ALSØ CØMPUTE PRØFILE PARAMETERS, ELECTRØN CØNTENT
C          =3 ALSØ CØMPUTE RANGE CØRRECTIØN
C          =4 ALSØ CØMPUTE RANGE RATE CØRRECTIØN
C  IDEL  = SELECTIØN FLAG FØR ELEVATIØN CØRRECTIØN, =0 CØMPUTE, =1 NØT
C  IØRD  = FLAG FØR CØRRECTIØN TØ RANGE DIFFERENCING,=1 FØR RANGE
C          CØRRECTIØN TØ 2. PØINT, =0 ØTHERWISE
C  IUPDT = UPDATE FLAG, =0 NØ UPDATE, =1 UPDATE
C  ITP   = UNIT ASSIGNMENT ØF IØNØSPHERIC CØEFFICIENT TAPE
C
      CØMMØN /UPDT/ ULAT,ULØN,ULEV,UZIM,UT,ØBS,ITYP,NUPDT
C  ULAT  = ARRAY WITH LATITUDES ØF UPDATE STATIØNS (RADIANS)
C  ULØN  = ARRAY WITH LØNGITUDES ØF UPDATE STATIØNS (RADIANS)
C  ULEV  = ARRAY WITH ELEVATIØNS TØ SATELLITE (RADIANS)
C  UZIM  = ARRAY WITH AZIMUTHS TØ SATELLITE (RADIANS)
C  UT    = ARRAY WITH UNIVERSAL TIMES ØF ØBSERVATIØNS (RADIANS)
C  ØBS   = ARRAY WITH IØNØSPHERIC ØBSERVATIØNS (MHZ ØR E/M**2)
C  ITYP  = ARRAY WITH ØBSERVATIØN TYPES,=1 FØF2,=2 VERT.E.C.,=3 ANGL.E.C.
C  NUPDT = NUMBER ØF UPDATE CØNDITIØNS
C
      CØMMØN /CØRR/DRANG,DRATE,DELEV,FØF2,HM,YM,YT,XK,TØTN,TØTNA
C  DRANG = RANGE CØRRECTIØN IN METERS
C  DRATE = RANGE RATE CØRRECTIØN IN METERS/SECØND
C  DELEV = ELEVATIØN ANGLE CØRRECTIØN IN RADIANS ØF ARC
C          RANGE, RANGE RATE, AND ELEVATIØN ANGLE CØRRECTIØNS ARE TØ BE
C          SUBTRACTED FRØM THEIR RESPECTIVE ØBSERVATIØNS
C  FØF2  = CRITICAL FREQUENCY (MHZ)
C  HM    = HEIGHT AT MAXIMUM ELECTRØN DENSITY (M)
```

```
C   YM    = HALF THICKNESS OF THE BOTTOMSIDE BIPARABOLA (M)
C   YT    = HALF THICKNESS OF THE TOPSIDE PARABOLA (M)
C   XK    = ARRAY CONTAINING DECAY CONSTANTS FOR THE LOWER, MIDDLE AND
C           UPPER SECTION OF THE TOPSIDE EXPONENTIAL LAYER (1/M)
C   TOTN  = VERTICAL ELECTRON CONTENT (E/M**2)
C   TOTNA= ANGULAR ELECTRON CONTENT (E/M**2)
C
      DIMENSION ULAT(8),ULON(8),ULEV(8),UZIM(8),ITYP(8),OBS(8)
      DIMENSION UT(8),FACF2(8),W(8,3),WT(8),XK(3),D3(3)
      DIMENSION WCOEF(3,13,76),U(13,76),UM(9,49),UM1(9,49)
      DATA MONDY,MOND,LYRMO/0,10000,0/
      DATA R,STRS,TOL/6371.2E3,36.E6,1.E-6/
      DATA Q0,Q1,Q100,Q130,QP1,QNM,RN3,PI,PI2/0.  ,1.  ,100.  ,130.  ,
     *.1  ,1.24E10,.49972  ,3.1415926536  ,6.2831853072  /
C
C         INITIALIZE CONSTANTS
      DELEV=Q0
      DRANG=Q0
      DRATE=Q0
      TOTN =Q0
      TOTNA=Q0
      IFLAG=0
      ISKIP=0
      IYRMO=IYR*100+MON
      IMODY=MON*100+IDAY
C
C         READ COEFFICIENT TAPE AND FORM COEFFICIENT ARRAYS
   10 IF(IMODY.LE.MONDY.AND.IMODY.GE.MOND) GO TO 29
   20 READ(ITP) LOND,LONDY,WCOEF,UM,UM1
      IF(EOF,ITP) 23,22
   22 ISKIP=1
      MOND=LOND
      MONDY=LONDY
      GO TO 10
   23 REWIND ITP
      IFLAG=IFLAG+1
      IF(IFLAG.LE.1) GO TO 20
      WRITE(6,25) IYR,MON,IDAY
   25 FORMAT(54H ***COEFFICIENTS NOT FOUND ON TAPE FOR YEAR,MONTH,DAY=,
     *3I3)
      IYR=-1
      GO TO 140
   29 IF(ISKIP.EQ.0.AND.IYRMO.EQ.LYRMO) GO TO 80
      LYRMO=IYRMO
      DO 62 J=1,49
      DO 62 I=1,9
      UM(I,J)=UM(I,J)+(UM1(I,J)-UM(I,J))*SIS/Q100
   62 CONTINUE
      DO 70 J=1,76
      DO 70 I=1,13
   70 U(I,J)=WCOEF(1,I,J)+(WCOEF(2,I,J)+WCOEF(3,I,J)*SIF)*SIF
   80 CONTINUE
```

```
C
C         PREPARE SØLAR DATA
      FLUX=FLXO
      IF(FLUX.LT.Q91)    FLUX=SIF
      DFLUX=FLUX-SIF
      IF(FLUX.GT.Q130)    FLUX=Q130
C
C      CØMPUTE FIRST PART ØF PRØFILE
      CALL PRØFL1(FLAT,FLØN,ELEV,AZ,TIME,DFLUX,U,UM,
     *            ØLAT,ØLØN,FOF2,HM,HLAT)
      IF(IUPDT.EQ.0) GØ TØ 115
      IF(NUPDT.EQ.0) GØ TØ 115
C
C         UPDATE CØMPUTED FOF2 WITH ANY ØF FØLLØWING IØN. ØBSERVATIØNS,
C         ITYP(I)=1 FOF2, =2 VERT.ELECTRØN CØNTENT, =3 ANGL.CØNTENT
C         UP TØ 8 MEASURED ENTRIES CAN BE USED FØR THE UPDATE PRØCESS
      DØ 90 I=1,NUPDT
      ØBSERV=ØBS(I)
      IF( TYP(I).LE.2) GØ TØ 85
      ØBSERV=ØBSERV* SQRT(Q1-(R* CØS(ULEV(I))/(R+HM))**2)
   85 CALL PRØFL1(ULAT(I),ULØN(I),ULEV(I),UZIM(I),UT(I),DFLUX,U,UM,
     *            TLAT,TLØN,STF2,STHM,STHLAT)
      IF(ITYP(I).GT.1) CALL PRØFL2(TLAT,TLØN,STRS,UT(I),IDAY,MØN,FLUX,
     *STF2,STHM,STHLAT,    D1,D2,D3,D4,SLAB)
      FACF2(I)=ØBSERV/STF2
      IF(ITYP(I).GE.2) FACF2(I)= SQRT(FACF2(I)/(QNM*STF2*SLAB))
      IF(NUPDT.EQ.1) GØ TØ 110
C
C         FØRM WEIGHTS FØR MULTIPLE UPDATE STATIØNS
      W(I,1)= ABS(TIME-UT(I))
      IF(W(I,1).GT.PI) W(I,1)=PI2-W(I,1)
      CANG= SIN(TLAT)* SIN(ØLAT)+ CØS(TLAT)* CØS(ØLAT)* CØS(TLØN-ØLØN)
      SANG= SQRT(Q1-CANG**2)
      W(I,2)= ABS( ATAN(SANG/CANG))
   90 W(I,3)=W(I,1)*W(I,2)
C
C         DETERMINE WEIGHTS TØ BE USED
      M1=0
      M2=0
      DØ 95 I=2,NUPDT
      IF( ABS(W(1,1)-W(I,1)).GT.TØL) M1=1
      IF( ABS(W(1,2)-W(I,2)).GT.TØL) M2=2
   95 CØNTINUE
      MARK=M1+M2
      IF(MARK.EQ.0) GØ TØ 110
C
C         CØMBINE WEIGHTS AND APPLY TØ UPDATE RATIØ
      DØ 100 I=1,NUPDT
      WT(I)=Q1
      DØ 100 J=1,NUPDT
      IF(I.EQ.J) GØ TØ 100
      WT(I)=WT(I)*W(J,MARK)
  100 CØNTINUE
```

```
      CØEF=Q0
      FUNC=Q0
      DØ 105 I=1,NUPØT
      CØEF=CØEF+AT(I)
  105 FUNC=FUNC+AT(I)*FACF2(I)
      FACF2(1)=FUNC/CØEF
C
C        UPDATE FØF2 ØF EVALUATIØN CØNDITIØN
  110 FØF2=FØF2*FACF2(1)
  115 CØNTINUE
      IF(IØPT.EQ.1) GØ TØ 140
C
C        CØMPUTE SECØND PART ØF PRØFILE
      CALL PRØFL2(BLAT,BLØN,HS,TIME,IDAY,MØN,FLUX,FØF2,HM,HLAT,
     *             YM,YT,XK,RRM,XNTNM)
      IF(XNTNM.LE.Q0) GØ TØ 140
C
C        CØMPUTE ELEVATIØN ANGLE CØRRECTIØN DELEV
      FRAT=(FØF2/FS)**2
      SE= SIN(ELEV)
      CE= CØS(ELEV)
      IF(IDEL.NE.0.ØR.IDRD.EQ.1) GØ TØ 120
      CALL BETA(FRAT,XNTNM,HS,HM,YM,SE,CE,DELEV)
C
C        CØMPUTE VERTICAL AND ANGULAR ELECTRØN CØNTENT TØTN,TØTNA
C        CØMPUTE RANGE CØRRECTIØN DRANG
  120 CØNTINUE
      RAT=(R/(R+ HM))**2
      DEN2=Q1-RAT* CE**2
      DEN= SQRT(DEN2)
      TØTN=XNTNM*QNM*FØF2**2
      TØTNA=TØTN/DEN
      IF(IØPT.LT.3) GØ TØ 140
      DRANG=FRAT*RN3*XNTNM/DEN
C
C        CØMPUTE RANGE RATE CØRRECTIØN DRATE
      IF(IØPT.LT.4.ØR.IDRD.EQ.1) GØ TØ 140
      DRATE=DRANG*EDØT*RAT*SE*CE/DEN2
      DRATE=DRATE-FRAT*RN3*HDØT*RRM/DEN
  140 CØNTINUE
      RETURN
      END
```

```
C
C     PLOT AND PRINT ELECTRON DENSITY VERSUS HEIGHT PROFILE
C     INPUT: FOF2 IN MHZ,  HM,YM,YT    IN METER, XK IN 1/METER
C
      SUBROUTINE PLOTNH (FOF2, HM,YM,YT,XK)
      DIMENSION XK(3),J(73),H(2),IH(2),XN(2),HT(5),ED(5)
      DATA G0,G1,IBLANK,MARK/0.   ,1.   ,1H ,1H*/
      DATA G3,G10,G27,G124E,G1012E,G1025E,G2025E,G25E/3.   ,10.   ,27.   ,
     *1.24E10,1012.E3,1025.E3,2025.E3,25.E3/
      WRITE(6,1)
C
C     COMPUTE PROFILE CONSTANTS
      D = -(G1- SQRT(G1+(XK(1)*YT)**2))/XK(1)
      HT(5)= HM-YM
      HT(4)= HM
      HT(3)= HM+D
      DELH=( G1012E-HT(3))/G3
      HT(2)=HT(3)+DELH
      HT(1)=HT(2)+DELH
      ED(5)= G124E *FOF2**2
      ED(4)=ED(5)
      ED(3)=ED(4)*(G1-(D/YT)**2)
      ED(2)=ED(3)* EXP(XK(1)*(HT(3)-HT(2)))
      ED(1)=ED(2)* EXP(XK(2)*(HT(2)-HT(1)))
C
C     INITIALIZE LOOP FOR PLOT
      H(1)=G1025E
      H(2)=G2025E
      IH(1)=1025
      IH(2)=2025
      DO 130 I=1,40
      DO 90 K=1,2
      H(K)=H(K)-G25E
      IH(K)=IH(K)-25
C
C     COMPUTE ELECTRON DENSITY AT HEIGHT H
      DO 10 L=1,5
      IF(H(K).GE.HT(L)) GO TO 20
   10 CONTINUE
      ZN=G0
      GO TO 80
   20 DH=H(K)-HT(L)
      GO TO (30,40,50,60,70),L
   30 ZN= EXP(-XK(3)*DH)
      GO TO 80
   40 ZN= EXP(-XK(2)*DH)
      GO TO 80
   50 ZN= EXP(-XK(1)*DH)
      GO TO 80
   60 ZN=G1-(DH/YT)**2
      GO TO 80
   70 ZN=(G1-(G1-DH/YM)**2)**2
```

```
   80 XN(K)=ED(L)*ZN
   90 CØNTINUE
C
C     PLØT AND PRINT
      XNL=0.0
      IF(XN(1).LE.0.0) GØ TØ 100
      XNL= LØG10(XN(1))
  100 CØNTINUE
      DØ 110 L=1,73
  110 J(L)=IBLANK
      NØ=(XNL-G10)*027+01
      IF(NØ.LT.1.ØR.NØ.GT.73) GØ TØ 120
      J(NØ)=MARK
  120 WRITE(6,2) IH(1),J,XN(1),IH(2),XN(2)
  130 CØNTINUE
      WRITE(6,3)
    1 FØRMAT  (1H1,11HHEIGHT (KM),51X,57HVERSUS ELECTRØN DENSITY (E/M**3
     *)     HEIGHT VS. EL.DENSITY)
    2 FØRMAT(1X,I4,2H *,73A1,4H*** ,D11.4,5X,I4,5H *** ,D11.4)
    3 FØRMAT(7X,2(1H+,17(1H-),1H+,8(1H-)),1H+,17(1H-),1H+/
     *5X,5H1.E10,22X,5H1.E11,22X,5H1.E12/
     *30X,37HLØG.SCALE - ELECTRØN DENSITY (E/M**3))
      RETURN
      END
```

```
C
C        CØMPUTE FIRST PART ØF PRØFILE: CRITICAL FREQUENCY FØF2 AND
C                                            CØRRESPØNDING HEIGHT HM
      SUBRØUTINE PRØFL1(FLAT,FLØN,ELEV,AZ,TIME,DFLUX,U,UM,
     *                  ØLAT,ØLØN,FØF2,HM,HLAT)
      DIMENSIØN K(10),U(13,76),KN(10),UM(9,49),CØT(6),SIT(6),P(3),CØM(3)
     *,C(3),G(76),DF(76),GM(49),DM(49)
      DIMENSIØN       DG(3)       ,CENT(3)
      DATA K/11,35,53,63,67,69,71,73,75,6/, KM10/4/
      DATA KN/1,7,13,26,37,48,55,60,65,72/,NFF,NMF/76,49/
      DATA G1,G1000,G3T5/1.  ,1000.  ,300000.  /
      DATA D180,D3/3.1415926536  ,1.02974426  ,.4886921   ,-.57595865  /
      DATA R,SPLAT,CPLAT,PLØN/6371.2E3,.979246,.1993684,5.07890E/
      DATA H1,H2,H3/1346.92  ,526.4  ,59.825  /
      DATA PER,CENT/.00133  ,1.035  ,.957  ,.9  /
C
      P(3)=G3T5
      SLAT= SIN(FLAT)
      CLAT= CØS(FLAT)
      SEL= SIN(ELEV)
      CEL= CØS(ELEV)
      SAZ= SIN(AZ)
      CAZ= CØS(AZ)
C
C        CØMPUTE TIME DEPENDENT FUNCTIØNS FØR FØF2 AND M3000
      T=TIME-D180
      CALL SICØJT(6,CØT,SIT,T)
      CALL DKSIØM(NFF,K(10),U,SIT,CØT,DF)
      CALL DKSIØM(NMF,KM10  ,UM,SIT,CØT,DM)
C
C        CØMPUTE LATITUDE, LØNGITUDE ØF IØNØSPHERIC PØINT ØLAT,ØLØN
   23 CØNTINUE
      SF=R*CEL/(R+P(3))
      CF= SQRT(G1-SF*SF)
      SA = CEL * CF - SEL * SF
      CA = SEL * CF + CEL * SF
      SNLAT=SLAT*CA+CLAT*SA*CAZ
      CNLAT= SQRT(G1-SNLAT*SNLAT)
      ØLAT= ATAN(SNLAT/CNLAT)
      SDLØN=SAZ*SA/CNLAT
      CDLØN= SQRT(G1-SDLØN*SDLØN)
      ØLØN=FLØN+ ATAN(SDLØN/CDLØN)
C
C        CØMPUTE PØSITIØN DEPENDENT FUNCTIØNS FØR FØF2 AND M3000
      P(1)=ØLAT
      P(2)=ØLØN
      CALL MAGFIN(P,CØM)
      TMP=CØM(2)*CØM(2)+CØM(3)*CØM(3)
      C(2)=P(2)
      C(3)=P(1)
      C(1)= ATAN( ATAN(-CØM(1)/ SQRT(TMP))/ SQRT(CNLAT))
      CALL GK(P,C,3)
```

```
      KK = 0
      DO 15 II=1,10,2
      I1=KN(II)
      I2=KN(II+1)
      DO 15 J=I1,I2
      KK = KK + 1
   15 GM(KK)=G(J)
C
C        COMPUTE H3000 AND HEIGHT OF MAX. ELECTRON DENSITY HM
      CALL DKCK(NMF,GM,DM,H3000)
      HM =(H1-H2*H3000+H3*H3000*H3000)*01000
      IF( ABS(P(3)- HM).LT.01000) GO TO 24
      P(3)= HM
      GO TO 23
C
C        COMPUTE FOF2 AND ADJUST FOF2 FOR DAILY VARIATION WITH FLUX
   24 CONTINUE
      CALL DKGK(NFF,G,DF,FOF2)
      SML = SNLAT * SPLAT + CNLAT * CPLAT *  COS( PLAN-PLAN)
      CML= SQRT(1-SML*SML)
      HLAT= ATAN(SML/CML)
      LAT1 = 1
      LAT2 = 1
      IF(HLAT.GE.DG(LAT2)) GO TO 21
      LAT2 = 2
      IF(HLAT.GT.DG(LAT2)) GO TO 21
      LAT1 = 2
      IF(HLAT.EQ.DG(LAT2)) GO TO 21
      LAT2 = 3
      IF(HLAT.LT.DG(LAT2)) GO TO 21
      LAT1 = 3
   21 CNT = CENT(LAT1)
      IF(LAT1.EQ.LAT2) GO TO 22
      CNT = CNT + (CENT(LAT2)-CENT(LAT1)) * (DG(LAT1)-HLAT)
     *         / (DG(LAT1)-DG(LAT2))
   22 FOF2 = FOF2 * (PER*DFLUX + CNT)
      RETURN
      END
```

PROFL2, CPC No. 5

```
C
C      COMPUTE SECOND PART OF PROFILE; PARAMETERS YM,YT,XK, RATIO OF
C      EL.CONTENT TO EL.DENSITY XNTNM, RANGE RATE MULTIPLIER RRM
      SUBROUTINE PROFL2(BLAT,BLON,HS,TIME,IDAY,MON,FLUX,FOF2,HM,HLAT,
     *                 YM,YT,XK,RRM,XNTNM)
      DIMENSION YMTAB(12,9),CEPT(4,3,3),SLOP(4,3,3),H(4),DH(3),XK(3)
      DIMENSION DEG(3)
      DIMENSION RATK(4,4,3)
      DIMENSION YRAT(7,6)
      DATA Q0,Q1,Q2,Q3,Q4,Q5,Q6,Q8,Q24,Q37,Q1000,QP05,QP1333,QP95,Q2P5,
     *Q10P5,Q8918/      0.  ,1.  ,2.  ,3.  ,4.  ,5.  ,6.  ,8.  ,24.  ,
     *37.  ,1000.  ,.05   ,.133333   ,.95   ,2.5   ,10.5   ,.533333333   /
      DATA D5,D7P5,D8,D10,D16,D30,D135,D180,PIH,PI2,DEG/
     *.0872664625   ,.13089969375   ,.13962634   ,.174532925   ,
     *.27925268   ,.523598775   ,2.35619449   ,3.1415926536   ,
     *1.5707963268   ,6.2831853072   ,1.3089969375   ,.7853981625   ,
     *.2617993875   /
      DATA SP1,SP2,RN4,H1012/.409'749893   ,.0172142063   ,.9375   ,
     *1012000.   /
      DATA CEPT/12.2E-6,8.73E-6,13.45E-6,15.45E-6,8.88E-6,10.38E-6,9.E-6
     *,10.94E-6,2.3E-6,9.56E-6,11.9E-6,12.84E-6,7.62E-6,4.67E-6,5.86E-6,
     *5.86E-6,1.1E-6,3.34E-6,4.42E-6,3.98E-6,.8E-6,3.16E-6,4.41E-6,4.54E
     *-6,3.92E-6,3.58E-6,4.06E-6,4.06E-6,.65E-6,1.52E-6,1.44E-6,1.95E-6,
     *.5E-6,2.74E-6,1.22E-6,1.55E-6/
      DATA SLOP/-7.5E-8,-3.6E-8,-9.E-8,-9.E-8,-3.1E-8,
     *-3.6E-8,-1.E-8,-1.8E-8,
     *4.5E-8,-1.6E-8,-3.5E-8,-2.4E-8,-3.4E-8,-.4E-8,-1.2E-8,-1.2E-8,
     *3.E-8,1.2E-8,.6E-8,1.4E-8,2.5E-8,1.3E-8,1.3E-8,1.7E-8,-.9E-8,
     *-.6E-8,-.7E-8,-.7E-8,1.5E-8,1.1E-8,1.7E-8,1.E-9,1.E-8,.8E-8,1.6E-8
     *,1.5E-8/
      DATA RATK/.82,.95,1.07,1.14,.86,.85,.9,1.05,.88,.975,1.05,1.125,
     *.94,1.1,1.115,1.115,.95,.97,.96,1.04,.94,.985,.975,1.005,1.125,
     *1.11,1.065,1.065,.99,1.175,1.08,.94,.985,.9,.86,.995,.925,1.055,
     *.97,.94,1.025,1.09,1.055,.93,.945,.885,.83,.84/
      DATA YMTAB/87.7,93.0,97.8,102.0,102.3,99.4,95.1,91.3,88.0,86.8,
     *86.0,85.2,      96.2,98.0,103.8,109.5,112.5,112.5,107.5,101.2,96.2,
     *95.4,97.0,98.1,      107.6,117.7,140.1,150.4,153.3,154.0,150.0,
     *140.2,127.1,115.5,109.2,106.5,      114.4,125.5,144.2,162.7,175.6,
     *180.6,174.8,157.5,134.7,115.0,110.1,110.0,      113.3,120.7,134.9,
     *158.2,161.6,190.5,177.0,152.5,123.0,113.4,111.5,110.3,      113.5,
     *125.4,139.0,158.6,199.5,188.3,183.3,166.8,136.9,119.9,111.9,108.0,
     *      114.0,118.2,125.6,157.0,211.4,232.3,211.2,188.3,142.5,124.8,
     *116.8,112.5,      122.7,132.0,143.3,158.3,187.1,214.4,196.8,185.5,
     *152.5,130.0,120.7,117.6,      140.8,147.5,155.0,167.8,200.0,195.6,
     *187.0,166.3,144.4,138.7,137.7,137.5/
      DATA YRAT/1.25,1.12,1.04,.96,.92,.92,.92,
     11.1,1.06,.99,.88,.78,.73,.7,      1.3,1.21,1.02,.88,.81,.78,.78,
     21.09,1.04,1.01,.98,.98,.99,1.,      .95,.96,.97,1.,1.04,1.09,1.13,
     31.24,1.24,1.24,1.24,1.33,1.33,1.64/
      HLAT= ABS(HLAT)
      TLOC=TIME+BLON+PI2
      TLOC=AMOD(TLOC,PI2)
```

```
C
C        COMPUTE HALF THICKNESS YM
      T12=TLOC/D30
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT1.EQ.12) LT2=LT1
      IF(LT1.GE.1) GO TO 55
      LT1=12
   55 T1=T12-T1
      IF1=FOF2-QP95
      IF2=FOF2-QP05
      IF(IF1.LT.1) IF1=1
      IF(IF1.GT.9) IF1=9
      IF (IF2.LT.1) IF2=1
      IF(IF2.GT.9) IF2=9
      YM=(YMTAB(LT1,IF1)+(YMTAB(LT2,IF1)-YMTAB(LT1,IF1))*T1)*Q1000
      IF(IF1.EQ.IF2) GO TO 60
      YM2=(YMTAB(LT1,IF2)+(YMTAB(LT2,IF2)-YMTAB(LT1,IF2))*T1)*Q1000
      F1=IF1
      YM= YM+(YM2-YM)*(FOF2-F1-Q1)
   60 CONTINUE
C
C     COMPUTE DIFFERENCE BETWEEN AVER. AND DAILY SOLAR ZENITH ANGLE DSZA
      DAY=(MON-1)*30+IDAY-80
      DSZA=SO1* SIN(SO2*DAY)
      IF( ABS(OLAT).LT.SO1) GO TO 61
      IF( OLAT.LT.Q0) DSZA=-DSZA
      GO TO 62
   61 SANG=OLAT/SO1
      CANG= SQRT(Q1- ABS(SANG*SANG))
      DANG= ATAN(SANG/CANG)
      ASZA=SO1*(CANG+SANG*DANG)/PIH
      DSZA=ASZA- ABS( OLAT-DSZA)
C
C     APPLY SEASONAL EFFECT OF DSZA TO HALF THICKNESS YM
   62 S12=Q4-DSZA/D8
      IF1=S12
      S1=IF1
      S1=S12-S1
      IF2=IF1+1
      RAT=Q0
      IF(HLAT.LE.D5) GO TO 63
      T12=(TLOC+D7P5)/PIH
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT2.GT.4) LT2=1
      IF(LT1.LT.1) LT1=4
      RAT1=YRAT(IF1,LT1)+(YRAT(IF2,LT1)-YRAT(IF1,LT1))*S1
      RAT2=YRAT(IF1,LT2)+(YRAT(IF2,LT2)-YRAT(IF1,LT2))*S1
      RAT=RAT1+(RAT2-RAT1)*(T12-T1)
      IF(HLAT.GE.DEG(3)) GO TO 64
```

```
   63 T12=(TLØC+D135)/D180*Q1
      IF(T12.GT.Q1) T12=Q2-T12
      IF(T12.LT.Q0) T12=-T12
      RAT1=YRAT(IF1,5)+(YRAT(IF2,5)-YRAT(IF1,5))*S1
      RAT2=YRAT(IF1,6)+(YRAT(IF2,6)-YRAT(IF1,6))*S1
      RATM=RAT1+(RAT2-RAT1)*T12
      RAT=RATM+(RAT-RATM)*(HLAT-D5)/D10
      IF(HLAT.LE.D5) RAT=RATM
   64 YM=YM*RAT
C
C        CØMPUTE K-PARAMETERS XK
      FQF2 = RN4 * FØF2
      I1=2
      I2=2
      IF(HLAT-DEG(2))28,30,29
   28 I1=3
      IF(HLAT.LE.DEG(3))I2=3
      GØ TØ 30
   29 I2=1
      IF(HLAT.GE.DEG(1))I1=1
   30 J = (FQF2 + Q1)/Q3
      XF=Q0
      IF(J.GE.1) GØ TØ 35
      J=1
      GØ TØ 45
   35 IF(J.LT.4) GØ TØ 40
      J=4
      GØ TØ 45
   40 F1=J
      XF = (FQF2 + Q1)/Q3 - F1
   45 DØ 51 M=1,3
      SLP=(SLØP(J+1,I1,M)-SLØP(J,I1,M))*XF+SLØP(J,I1,M)
      CPT=(CEPT(J+1,I1,M)-CEPT(J,I1,M))*XF+CEPT(J,I1,M)
      IF(I1.EQ.I2) GØ TØ 50
      DEL=(HLAT-DEG(I1))/(DEG(I2)-DEG(I1))
      SLP=SLP+((SLØP(J+1,I2,M)-SLØP(J,I2,M))*XF+SLØP(J,I2,M)-SLP)*DEL
      CPT=CPT+((CEPT(J+1,I2,M)-CEPT(J,I2,M))*XF+CEPT(J,I2,M)-CPT)*DEL
   50 XK(M) = SLP * FLUX + CPT
   51 CØNTINUE
C
C     APPLY SEASØNAL EFFECT ØF DSZA TØ DECAY CØNSTANTS XK
      T12=TLØC/DEG(3)-Q8
      IF(T12.LT.Q0) T12=T12+Q24
      T12=T12/Q6+Q1
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT2.GT.4) LT2=1
      S12=Q2P5-DSZA/D16
      IF1=S12
      S1=IF1
      S1=S12-S1
      IF2=IF1+1
```

```
      DO 52 M=1,3
      RAT1=RATK(IF1,LT1,M)+(RATK(IF2,LT1,M)-RATK(IF1,LT1,M))*S1
      RAT2=RATK(IF1,LT2,M)+(RATK(IF2,LT2,M)-RATK(IF1,LT2,M))*S1
      RAT = RAT1 + (RAT2-RAT1) * (T12-T1)
   52 XK(M)=XK(M)*RAT
C
C        COMPUTE HALF THICKNESS OF TOPSIDE PARABOLA YT
      CONV=Q1
      IF(FOF2.LE.Q10P5) GO TO 71
      CONV=QP1333*(FOF2-Q10P5)+Q1
   71 CONTINUE
      YT=CONV*YM
C
C        COMPUTE HDOT MULTIPLIER FOR RANGE RATE COMPUTATION RRM
C        COMPUTE TOTAL ELECTRON CONTENT / ELECTRON DENSITY XNTNM
      XNTNM=Q0
      RRM=Q0
      D=-(Q1-SQRT(Q1+(XK(1)*YT)**2))/XK(1)
      H(1)=HM+D
      IF(HS.LE.H(1)) GO TO 80
      RRM=Q1
      DELH = (H1012 - H(1))/Q3
      H(2) = H(1) + DELH
      H(3)=H(2)+DELH
      H(4)=HS
      M=3
   65 IF(HS.GT.H(M)) GO TO 70
      H(M)=H(M+1)
      M=M-1
      IF(M.GT.1) GO TO 65
   70 DH(M)=H(M+1)-H(M)
      RK=Q1/XK(M)
      EX=Q0
      ARG=XK(M)*DH(M)
      IF(ARG.LT.Q37) EX= EXP(-ARG)
      RRM=RRM*EX
      XNTNM=RK+EX*(XNTNM-RK)
      M=M-1
      IF(M.GT.0) GO TO 70
      TEMP=Q8R15*YM+D-D**3/(Q3*YT*YT)
      TEMP1=Q1-(D/YT)**2
      RRM=RRM*TEMP1
      XNTNM=TEMP1*XNTNM+TEMP
      GO TO 110
   80 IF(HS.LE.( HM-YM)) GO TO 110
      DIST= HM-HS
      IF(HS.LT. HM) GO TO 90
      XNTNM=Q8R15*YM-DIST+DIST**3/(Q3*YT*YT)
      RRM=Q1-((HM-HS)/YT)**2
      GO TO 110
   90 CONTINUE
      XNTNM=Q8R15*YM-DIST+Q2*DIST**3/(Q3*YM**2)-DIST**5/(Q5*YM**4)
      RRM=(Q1-((HM-HS)/YM)**2)**2
```

```
110 CONTINUE
    RETURN
    END
```

```
C
      SUBROUTINE BETA(FRAT,XNTNM,HS,HM,YM,BE,CE,DELEV)
C
C        BETA COMPUTES IONOSPHERIC ELEVATION ANGLE CORRECTION TO BE
C        SUBTRACTED FROM MEASURED ELEVATION ANGLE
      DIMENSION XAX(5),YAX(5)
      DATA R,Q0,    Q1,Q5333,Q2/6371.2E3,0.   ,  1.E0,.5333E0,2.E0/
      DATA XAX/0.E0, .2E0, .4E0, .6E0,  .81E0/
      DATA YAX/1.E0,.924E0,.824E0,.7E0,.553E0/
      R2=R*R
      RS=HS+R
C
C        COMPUTE SQUARED DEVIATION FACTOR XCOM
      ROM=R+ HM
      SFIM=R*CE/ROM
      CFIM= SQRT(Q1-SFIM**2)
      XCOM=FRAT/CFIM**2
C
C        INTERPOLATE TABULATED VALUES YAX TO GET YCOM
      DO 30 I=1,5
      IF(XCOM-XAX(I))20,10,30
   10 YCOM=YAX(I)
      GO TO 40
   20 YCOM=YAX(I)+(YAX(I-1)-YAX(I))*(XCOM-XAX(I))/(XAX(I-1)-XAX(I))
      GO TO 40
   30 CONTINUE
      GO TO 50
   40 YCOM=Q1/YCOM
C
C        COMPUTE DEVIATION ANGLE ALPHA
      ROO=ROM+Q5333*YM
      SFIO=R*CE/ROO
      CFIO= SQRT(Q1-SFIO**2)
      ALPHA=FRAT*YCOM*XNTNM*SFIO/(Q2*ROO*CFIO**3)
C
C        COMPUTE ELEVATION ANGLE CORRECTION
      CA= COS(ALPHA)
      SA= SIN(ALPHA)
      X3=R*CE*SA/(Q1+CA)
      X2=R*SE-X3
      X1= SQRT(RS**2-R2*CE**2)+X3
      CTE=(X1*CA-X2)/ SQRT(X1**2+X2**2-Q2*X1*X2*CA)
      STE= SQRT( ABS(Q1-CTE**2))
      DELEV= ATAN(STE/CTE)
      RETURN
   50 WRITE(6,1)
    1 FORMAT(  112H *** RAY IS REFLECTED AT IONOSPHERE OR NEAR REFLECTIO
     *N CONDITION, ELEVATION ANGLE CORRECTION IS NOT COMPUTED ***)
      DELEV=Q0
      RETURN
      END
```

```
C
      SUBRØUTINE SICØJT(L,C,S,T)
C
C     CØMPUTE SIN(JT),CØS(JT),J=1,...,L FØR ANGLE A
C
      DIMENSIØN S(1),C(1)
      C(1)= CØS(T)
      S(1)= SIN(T)
      DØ 10 I=2,L
      C(I)=C(1)*C(I-1)-S(1)*S(I-1)
   10 S(I)=C(1)*S(I-1)+S(1)*C(I-1)
      RETURN
      END
```

```
C
      SUBRØUTINE DKSICØ (MX,LH,D,SITIME,CØTIME,DK)
C
C     CØMPUTE D SUB K,CØEFFICIENTS FØR A FIXED TIME
C
      DIMENSIØN D(1),CØTIME(1),SITIME(1),DK(1)
      LMAX=LH*2+1
      LK=1-LMAX
      DØ 5 K=1,MX
      LK=LK+LMAX
      DK(K)=D(LK)
      DØ 5 L=1,LH
      NK=LK+L*2
    5 DK(K)=DK(K)+D(NK-1)*SITIME(L)+D(NK)*CØTIME(L)
      RETURN
      END
```

```
C
      SUBROUTINE MAGFIN(POS,UNE)
C
C     COMPUTE NASA MAGNETIC FIELD COMPONENTS
C
      DIMENSION P(7,7),DP(7,7),CP(7),AOR(7),SP(7),POS(3),UNE(3),CT(7,7),
     .          G(7,7),H(7,7)
      DATA CT/2*0.,.33333333,.26666667,.25714286,.25396825,.25252525,
     .        3*0.,.20000000,.22857142,.23809523,.24242424,
     .        4*0.,.14285714,.19047619,.21212121,
     .        5*0.,.11111111,.16161616,
     .        6*0.,.09090909,
     .        7*0.,7*0./
      DATA G/  0., .304112, .024035,-.031518,-.041794, .016256,-.019523,
     .         0., .021474,-.051253, .062130,-.045298,-.034407,-.004853,
     .       2*0.,-.013381,-.024638,-.021795,-.019447, .003212,
     .       3*0.,-.006496, .007008,-.000608, .021413,
     .       4*0.,-.002044, .002775, .001051,
     .       5*0., .000697, .000227,
     .       6*0., .001115/
      DATA H/7*0.,
     .         0.,-.057989, .033124, .014870,-.011825,-.000796,-.005758,
     .       2*0.,-.001579,-.004075, .010006,-.002000,-.008735,
     .       3*0., .000210, .000430, .004597,-.003406,
     .       4*0., .001385, .002421,-.000118,
     .       5*0.,-.001218,-.001116,
     .       6*0.,-.000325/
      DATA P(1,1),DP(1,1),SP(1),CP(1)/1.,0.,0.,1./
      DATA RE,Z0,R899/6371200.E0,0.E0,1.56905099E0/
      P2=POS(2)
      P1=POS(1)
      IF( ABS(P1).LE.R899) GO TO 4
      P1= SIGN(R899,P1)
      P2=Z0
    4 CONTINUE
      AR=RE/(RE+ 300.E3)
      C= SIN(P1)
      S= SQRT(CP(1)-C*C)
      AOR(1)=AR*AR
C
C     COMPUTE SIN,COS FOR MULTIPLE LONGITUDE ANGLE
      CALL SICOUT(6,CP(2),SP(2),P2)
      DO 5 M=2,7
    5 AOR(M)=AR*AOR(M-1)
C
C     CLEAR OUTER SUMS AND SET UP LOOP
      BV=Z0
      BN=Z0
      BPHI=Z0
      DO 6 N=2,7
      FN=N
C
```

```
C      CLEAR INNER SUMS AND SET UP LOOP
       SUMR=0.
       SUMT=0.
       SUMP=0.
       DO 7 M=1,N
C
C      COMPUTE FUNCTIONS AND DERIVATIVES OF MULT.ASS.LEGENDRE FUNCTION
C      IS THIS LAST CONTRIBUTION TO INNER SUM
       IF(M.NE.N) GO TO 8
       P(N,N)=S*P(N-1,N-1)
       DP(N,N)=S*DP(N-1,N-1)+C*P(N-1,N-1)
       GO TO 10
 8     P(N,M)=C*P(N-1,M)-CT(N,M)*P(N-2,M)
       DP(N,M)=C*DP(N-1,M)-S*P(N-1,M)-CT(N,M)*DP(N-2,M)
 10    FM=M-1
       TS=G(N,M)*CP(M)+H(N,M)*SP(M)
C
C      SUM INTO INNER SUMS FOR Z,X,Y
       SUMR=SUMR+P(N,M)*TS
       SUMT=SUMT+DP(N,M)*TS
 7     SUMP=SUMP+FM*P(N,M)*(-G(N,M)*SP(M)+H(N,M)*CP(M))
C
C      SUM INTO OUTER SUMS FOR Z,X,Y
       BV=BV+AOR(N)*FN*SUMR
       BN=BN-AOR(N)*SUMT
 6     BPHI=BPHI-AOR(N)*SUMP
C
C      SET MAGNETIC FIELD COMPONENTS Z-VERTICAL UP,X-NORTH,Y-EAST
       UNE(1)=-BV
       UNE(2)=BN
       UNE(3)=-BPHI/S
       RETURN
       END
```

```
C
      SUBROUTINE GK (K,C,G)
C
C     COMPUTE COORDINATE FUNCTIONS,G(I),I=1,...,K+1
C     C(1)=MODIFIED LATITUDE,C(2),C(3)=GEOG.LONGITUDE,LATITUDE
C        G IS THE ARRAY FOR GEOGRAPHIC FUNCTIONS
C
      DIMENSION K(1),C(1),G(1)
      DATA G1/1.   /,N/8/
      X=C(1)
      Y=C(2)
      Z=C(3)
      KO=K(1)
      SX= SIN(X)
C
C     SET TERMS DUE TO MAIN LATITUDINAL VARIATION
      G(2)=SX
      G(1)=G1
      DO 10 I=2,KO
   10 G(I+1)=SX*G(I)
      KDIF=K(2)-KO
      J=1
      CX1= COS(Z)
      CX=CX1
      T=Y
   18 KC=K(J)+4
C
C     COMPUTE FIRST 2 TERMS OF J-TH ORDER LONGITUDINAL VARIATION
      G(KC-2)=CX* COS(T)
      G(KC-1)=CX* SIN(T)
C
C     ARE ONLY 2 TERMS TO BE COMPUTED FOR THIS ORDER LONGITUDE
      IF(KDIF.EQ.2) GO TO 28
      KN=K(J+1)
C
C     COMPUTE REMAINING TERMS OF J-TH ORDER LONGITUDE
      DO 22 I=KC,KN,2
      G(I)=SX*G(I-2)
   22 G(I+1)=SX*G(I-1)
C
C     ARE TERMS FOR MAXIMUM ORDER LONGITUDE COMPUTED
   28 IF(J.EQ.N) GO TO 80
C
C     PREPARE FOR NEXT ORDER LONGITUDE COMPUTATIONS
      KDIF=K(J+2)-K(J+1)
      IF(KDIF.EQ.0) GO TO 80
      CX=CX*CX1
      J=J+1
      FJ=J
      T=FJ*Y
      GO TO 18
   80 RETURN
      END
```

```
C
      SUBROUTINE DKGK(MX,G,DKSTAR,OMEGA)
C
C     COMPUTE OMEGA, SUMMING THE GEOGRAPHIC SERIES
C
      DIMENSION G(1),DKSTAR(1)
      OMEGA=G(1)*DKSTAR(1)
      DO 5 K=2,MX
    5 OMEGA=OMEGA+DKSTAR(K)*G(K)
      RETURN
      END
```

```
C
C     PROGRAM TABGEN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2)
C        PREPROCESSOR GENERATING FOF2-HM TABLES ON TAPE TO BE USED
C        WITH PROGRAM ION1
C        ITP=UNIT ASSIGNMENT OF INPUT TAPE WITH IONOSPHERIC COEFFICIENTS
C        JTP=UNIT ASSIGNMENT OF OUTPUT TAPE WITH ION. FOF2-HM TABLES
      DIMENSION JAZ(4),IFM(14,26),FLX(31)
      DIMENSION K(10),KN(10),COT(6),SIT(6),P(3),COM(3)
     *,C(3),G(76),DF(76),GM(49),DM(49)
      DIMENSION      DB(3)       ,CENT(3)
      DIMENSION WCOEF(3,13,76),U(13,76),UM(9,49),UM1(9,49)
      DATA JAZ/1,4,8,12/, ITP,JTP/1,2/
      DATA MONDY,MOND,LYRMO/0,10000,0/
      DATA K/11,35,53,63,67,69,71,73,75,6/, KM10/4/
      DATA KN/1,7,13,28,37,48,55,60,65,72/,NFF,NMF/76,49/
      DATA    Q1,Q10,Q100,Q130,Q3T5,QP1,QP5/      1.  ,10.  ,100.  ,130.
     * ,300000.  ,.1  ,.5  /
      DATA DR,PI2,D7,DHR1,DHR2/.0174532925  ,6.283185308  ,.1221730476
     *,.2617993878  ,.5235987756  /
      DATA D180,D3/3.1415926536  ,1.02974426  ,.48869219  ,-.57595865  /
      DATA PER,CENT/.00133  ,1.035  ,.957  ,.9  /
      DATA   SPLAT,CPLAT,PLON/          .9799246,.1993684,5.078908/
      DATA H1,H2,H3/1346.92  ,526.4  ,59.825  /
      P(3)=Q3T5
C
C        LOOP OVER CONDITIONS
  100 CONTINUE
C
C        READ DATE AND STATION POSITION FROM CARD
      READ(5,1) IYR,MON,IDAY,FLAT,FLON
    1 FORMAT(3I5,2F10.5)
      IF(IYR.LE.0) GO TO 900
      WRITE(6,2) IYR,MON,IDAY,FLAT,FLON
    2 FORMAT(//75H GENERATE RECORD ON OUTPUT TAPE CONTAINING IONOSPHERIC
     * FOF2-HM TABLES FOR   /6H YEAR=,I2,8H, MONTH=,I2,6H, DAY=,I2,11H, L
     *ATITUDE=,F10.5,27H DEG, LONGITUDE OF STATION=,F10.5,4H DEG)
      FLAT=FLAT*DR
      FLON=FLON*DR
      IFLAG=0
      ISKIP=0
      IYRMO=IYR*100+MON
      IMODY=MON*100+IDAY
C
C        READ COEFFICIENT TAPE
   10 IF(IMODY.LE.MONDY.AND.IMODY.GE.MOND) GO TO 25
   20 READ(ITP) LOND,LONDY,WCOEF,UM,UM1
      IF(EOF,ITP) 23,22
   22 ISKIP=1
```

```
      MOND=LOND
      MONDY=LONDY
      GO TO 10
   23 REWIND ITP
      IFLAG=IFLAG+1
      IF(IFLAG.LE.1) GO TO 20
      WRITE(6,25) IYR,MON,IDAY
   25 FORMAT(54H ***COEFFICIENTS NOT FOUND ON TAPE FOR YEAR,MONTH,DAY=,
     *3I3)
      GO TO 400
   29 IF(ISKIP.EQ.0.AND.IYRMO.EQ.LYRMO) GO TO 80
C
C         READ SOLAR DATA
      IF(IYRMO.EQ.LYRMO) GO TO 55
      READ(5,7)IYM1,(FLX(I),I=1,16),IYM2,(FLX(I),I=17,31),IYM3,SIS,SIF
    7 FORMAT(I4,4X,16F4.1/I4,15F4.1/I4,2F5.1)
      IF(IYM1.EQ.IYM2.AND.IYM2.EQ.IYM3.AND.IYM3.EQ.IYRMO) GO TO 50
      WRITE(6,8)IYR,MON
    8 FORMAT(//39H ***ERROR IN SOLAR INPUT DATA FOR YEAR=,I2,11H AND MON
     *TH=,I2)
      GO TO 400
   50 LYRMO=IYRMO
C
C         PREPARE SPECIFIC COEFFICIENT SETS
   55 DO 62 J=1,49
      DO 62 I=1,9
      UM(I,J)=UM(I,J)+(UM1(I,J)-UM(I,J))*SIS/Q100
   62 CONTINUE
      DO 70 J=1,76
      DO 70 I=1,13
   70 U(I,J)=WCOEF(1,I,J)+(WCOEF(2,I,J)+WCOEF(3,I,J)*SIF)*SIF
C
C         PREPARE SOLAR DATA
   80 FLXD=FLX(IDAY)
      WRITE(6,15)FLXD,SIF,SIS
   15 FORMAT(12H DAILY FLUX=,F6.1,41H, 12-MONTH RUNNING AVERAGE OF SOLAR
     * FLUX=,F6.1,20H, OF SUNSPOT NUMBER=,F6.1)
      FLUX=FLXD
      IF(FLUX.LT.QP1)   FLUX=SIF
      DFLUX=FLUX-SIF
      IF(FLUX.GT.Q130)   FLUX=Q130
C
C         GENERATE 25 POINT PATTERN AROUND STATION
C         LOOP OVER EARTH CENTRAL ANGLES
      ECA=-D7
      N=0
      DO 300 ICA=1,4
      ECA=ECA+D7
      SA= SIN(ECA)
      CA= COS(ECA)
      NAZ=JAZ(ICA)
      DAZ=NAZ
      DAZ=PI2/DAZ
```

```
      AZ=-DAZ
C
C        LOOP OVER AZIMUTH
      DO 300 IAZ=1,NAZ
      M=M+1
      AZ=AZ+DAZ
      SAZ= SIN(AZ)
      CAZ= COS(AZ)
C
C        COMPUTE LATITUDE, LONGITUDE OF IONOSPHERIC POINT OLAT,OLON
      SNLAT= SIN(FLAT)*CA+ COS(FLAT)*SA*CAZ
      CNLAT= SQRT(D1-SNLAT*SNLAT)
      OLAT= ATAN(SNLAT/CNLAT)
      SOLON=SAZ*SA/CNLAT
      COLON= SQRT(D1-SOLON*SOLON)
      OLON=FLON+ ATAN(SOLON/COLON)
C
C        COMPUTE POSITION DEPENDENT FUNCTIONS FOR FOF2 AND M3000
      P(1)=OLAT
      P(2)=OLON
      CALL MAGFIN(P,COM)
      TMP=COM(2)*COM(2)+COM(3)*COM(3)
      C(2)=P(2)
      C(3)=P(1)
      C(1)= ATAN( ATAN(-COM(1)/ SQRT(TMP))/ SQRT(CNLAT))
      CALL GK(K,C,3)
      KK = 0
      DO 85 II=1,10,2
      I1=KN(II)
      I2=KN(II+1)
      DO 85 J=I1,I2
      KK = KK + 1
   85 GM(KK)=G(J)
C
C        COMPUTE MAGNETIC LATITUDE OF IONOSPHERIC POINT
      SML = SNLAT * SPLAT + CNLAT * CPLAT *  COS( OLON-PLON)
      CML= SQRT(D1-SML*SML)
      MLAT= ATAN(SML/CML)
C
C        LOOP OVER 14 LOCAL HOURS
      TLOC=-DHR2
      DO 200 IH=1,14
      DHR=DHR2
      IF(IH.GE.4.AND.IH.LE.7) DHR=DHR1
      TLOC=TLOC+DHR
      TIME=TLOC-OLON+PI2
      TIME=AMOD(TIME,PI2)
C
C        COMPUTE TIME DEPENDENT FUNCTIONS FOR FOF2 AND M3000
      T=TIME-D180
      CALL BICOUT(6,COT,SIT,T)
      CALL DKSICO(NFF,K(10),U,SIT,COT,DF)
      CALL DKSICO(NMF,KM10  ,UM,SIT,COT,DM)
```

```
C
C         COMPUTE H3000 AND HEIGHT OF MAX. ELECTRON DENSITY HM
      CALL DK3K(NMF,3M,DM,H3000)
      HM = H1-H2*H3000+H3*H3000*H3000
C
C         COMPUTE FOF2 AND ADJUST FOF2 FOR DAILY VARIATION WITH FLUX
      CALL DK3K(NFF,3,DF,FOF2)
      LAT1 = 1
      LAT2 = 1
      IF(HLAT.GE.D3(LAT2)) GO TO 91
      LAT2 = 2
      IF(HLAT.GT.D3(LAT2)) GO TO 91
      LAT1 = 2
      IF(HLAT.EQ.D3(LAT2)) GO TO 91
      LAT2 = 3
      IF(HLAT.GT.D3(LAT2)) GO TO 91
      LAT1 = 3
   91 CNT = CENT(LAT1)
      IF(LAT1.EQ.LAT2) GO TO 92
      CNT = CNT + (CENT(LAT2)-CENT(LAT1)) * (D3(LAT1)-HLAT)
     *        / (D3(LAT1)-D3(LAT2))
   92 FOF2 = FOF2 * (PER*DFLUX + CNT)
      IFH(IH,M)= HM*D10+OP5
      IF2=FOF2*D100+OP5
      IFH(IH,M)=IFH(IH,M)*10000+IF2
  200 CONTINUE
  300 CONTINUE
C
C         WRITE OUTPUT RECORD OF IONOSPHERIC FOF2-HM TABLES
      IYMD= IYR*10000+MON*100+IDAY
      WRITE(JTP) IYMD,FLAT,FLON,FLUX,IFH
      GO TO 100
  400 CONTINUE
      END FILE JTP
      REWIND JTP
      STOP
      END
```

```
C
      PROGRAM ION1  (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
C     COMPUTES IONOSPHERIC PROFILE PARAMETERS AND REFRACTION CORRECTIONS
C     UTILIZING PRECOMPUTED FOF2-HM TABLES
C    ***** TO BE USED ONLY FOR STRINGENT CORE SPACE AND/OR RUN TIME
C    ***** REQUIREMENTS, SINCE INTERPOLATIONS OF THE PRECOMPUTED FOF2-HM
C    ***** TABLES CREATE LESS ACCURATE RESULTS THAN THOSE OBTAINED
C    ***** FROM PROGRAM ION
C
C     CONTENT OF COMMON BLOCKS EXPLAINED IN SUBROUTINE REFRC1
      COMMON /EVAL1/ FS,FLAT,FLON,ELEV,AZ,HS,EDOT,HDOT,TIME,
     *IYR,MON,IDAY,JTP
      COMMON /CORR1/ DRANG,DRATE,DELEV,FOF2,HM,YM,YT,XK,TOTN,TOTNA
C
      DIMENSION XK(3)
      DATA Q0,Q1000,Q3600,DR,HR     /0.   ,1000.   ,3600.   ,.0174532925  ,
     *.2617993875  /
      JTP=2
      NUM=0
      WRITE(6,26)
   26 FORMAT(1H1)
   10 CONTINUE
C
C     RE D AND PRINT EVALUATION CONDITION
      READ(5,3)FS,FLAT,FLON
    3 FORMAT(F10.4,2F10.5)
      IF(FS.LT.Q0   ) GO TO 100
      READ(5,4)ELEV,AZ,HS,EDOT,HDOT
    4 FORMAT(2F10.6,F10.0,2E15.8)
      READ(5,5)IYR,MON,IDAY,TIME
    5 FORMAT(3I5,F10.7)
      WRITE(6,6)FS,FLAT,FLON,ELEV,AZ,HS,EDOT,IYR,MON,IDAY,TIME,HDOT
    6 FORMAT(    12H ** INPUT **//
     *              11H FREQUENCY=,F10.4,15H MHZ, LATITUDE=,F10.5,
     *27H DEG, LONGITUDE OF STATION=,F10.5,4H DEG/11H ELEVATION=,F10.6,
     *15H DEG,  AZIMUTH=,F10.6,27H DEG,  HEIGHT OF SATELLITE=,F11.1,
     *21H KM,  ELEVATION RATE=,E15.8,8H RAD/SEC/6H YEAR=,I2,8H, MONTH=,
     *I2,6H, DAY=,I2,10H,  U.TIME=,F10.7,5H HRS,,39X,15H ALTITUDE RATE=,
     *E15.8,6H M/SEC)
C
C     CONVERT UNITS
      FLAT=FLAT*DR
      FLON=FLON*DR
      ELEV=ELEV*DR
      AZ=AZ*DR
      HS=HS*Q1000
      TIME=TIME*HR
C
C     COMPUTE AND PRINT IONOSPHERIC DATA
      CALL REFRC1
      IF(IYR.LT.0) GO TO 10
      XHM=HM/Q1000
      WRITE(6,21) XHM,FOF2
```

```
 21 FORMAT( /13H ** OUTPUT **//35H HEIGHT AT MAXIMUM ELECTRON DENSITY,
   *10X,3HHM=,F8.3,30H KM,  CRITICAL FREQUENCY FOF2=,F7.3,4H MHZ)
    XYM=YM/Q1000
    XYT=YT/Q1000
    WRITE(6,22)TOTN,TOTNA,XYM,XYT,XK
 22 FORMAT(48H TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=,E13.6,
   *25H E/(M*M),    ANGULAR  NTA=,E13.6,15H E/(M*M COLUMN)/
   *48H HALF THICKNESS OF BOTTOMSIDE BIPARABOLA      YM=,F8.3,
   *30H KM,   OF TOPSIDE PARABOLA  YT=,F8.3,3H KM/
   *58H DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1=,
   *E12.5,12H, MIDDLE K2=,E12.5,11H, UPPER K3=,E12.5,4H 1/M)
    TELEV=DELEV*Q3600  /DR
    WRITE(6,23)TELEV
 23 FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=,
   *E13.6,11H SEC OF ARC)
    WRITE(6,24) DRANG
 24 FORMAT(43H IONOSPHERIC REFRACTION CORRECTION TO RANGE,10X,1H=,
   *E13.6,2H M)
    WRITE(6,25) DRATE
 25 FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE      =,
   *E13.6,6H M/SEC)
    NUM=NUM+1
    IF(NUM.LT.3) GO TO 27
    WRITE(6,26)
    NUM=0
    GO TO 10
 27 WRITE(6,28)
 28 FORMAT(//)
    GO TO 10
100 CONTINUE
    STOP
    END
```

```
C
C        IONOSPHERIC REFRACTION MODEL UTILIZING PRECOMPUTED FOF2-HM
C        TABLES FOR INTERPOLATION
C      ***** TO BE USED ONLY FOR STRINGENT CORE SPACE AND/OR RUN TIME
C      ***** REQUIREMENTS
       SUBROUTINE REFRC1
C
C    INPUT: COMMON /EVAL1/
C    OUTPUT: COMMON /CORR1/
C
       COMMON /EVAL1/ FS,FLAT,FLON,ELEV,AZ,HS,EDOT,HDOT,TIME,
      *IYR,MON,IDAY,JTP
C   FS    = TRANSMISSION FREQUENCY IN MHZ
C   FLAT  = STATION LATITUDE IN RADIANS OF ARC
C   FLON  = STATION LONGITUDE IN RADIANS OF ARC (POSITIVE EAST,0 TO 360 D)
C   ELEV  = ELEVATION OF SATELLITE IN RADIANS OF ARC
C   AZ    = AZIMUTH OF SATELLITE IN RADIANS OF ARC
C   HS    = HEIGHT OF SATELLITE IN METERS
C   EDOT  = ELEVATION RATE IN RADIANS OF ARC/SECOND
C   HDOT  = RATE OF CHANGE IN HEIGHT OF SATELLITE IN METERS/SECOND
C   TIME  = UNIVERSAL TIME IN RADIANS OF ARC
C   IYR   = YEAR (LAST 2 DIGITS ONLY)
C   MON   = MONTH (=1 THROUGH 12)
C   IDAY  = DAY (=1 THROUGH 31)
C   JTP   = UNIT ASSIGNMENT OF IONOSPHERIC TAPE WITH FOF2-HM TABLES
C
       COMMON /CORR1/ DRANG,DRATE,DELEV,FOF2,HM,YM,YT,XK,TOTN,TOTNA
C   DRANG= RANGE CORRECTION IN METERS
C   DRATE= RANGE RATE CORRECTION IN METERS/SECOND
C   DELEV= ELEVATION ANGLE CORRECTION IN RADIANS OF ARC
C          RANGE, RANGE RATE, AND ELEVATION ANGLE CORRECTIONS ARE TO BE
C          SUBTRACTED FROM THEIR RESPECTIVE OBSERVATIONS
C   FOF2 = CRITICAL FREQUENCY (MHZ)
C   HM   = HEIGHT AT MAXIMUM ELECTRON DENSITY (M)
C   YM   = HALF THICKNESS OF THE BOTTOMSIDE BIPARABOLA (M)
C   YT   = HALF THICKNESS OF THE TOPSIDE PARABOLA (M)
C   XK   = ARRAY CONTAINING DECAY CONSTANTS FOR THE LOWER, MIDDLE AND
C          UPPER SECTION OF THE TOPSIDE EXPONENTIAL LAYER (1/M)
C   TOTN = VERTICAL ELECTRON CONTENT (E/M**2)
C   TOTNA= ANGULAR ELECTRON CONTENT (E/M**2)
C
       DIMENSION XK(3),LYMD(4),ALAT(4),ALON(4),FLXD(4),IFH(14,25,4)
       DIMENSION LT(2),MP(2),FT(2),HT(2),FI(2),HI(2),FA(2),HA(2),JAZ(4),
      *KAZ(4)
       DATA JAZ/1,4,8,12/, KAZ/1,2,6,14/, LYMD/0,0,0,0/, NO,NR/4,0/
       DATA R,SPLAT,CPLAT,PLON/6371.2E3,.9799246,.1993684,5.078908/
       DATA RM,TOL/6671200.   ,.0087266463  /
       DATA Q0,Q1,Q2,Q7,Q100,Q3P5,Q4P5,QNM,RN2,PI2,DR,HR/0.   ,1.   ,2.   ,
      *7.   ,100.   ,3.5   ,4.5   ,1.24E10,.49972   ,6.2831853072   ,
      *.0174532925   ,.2617993878   /
       EQUIVALENCE (LT(1),LT1),(LT(2),LT2),(MP(1),MP1),(MP(2),MP2)
C
```

```
C         INITIALIZE CONSTANTS
      DELEV=Q0
      DRANG=Q0
      DRATE=Q0
      TOTN= Q0
      TOTNA=Q0
      IFLAG=0
      NYMD=IYR*10000+MON*100+IDAY
C
C         READ FOF2-HM INTERPOLATION TABLES FROM FILE, SELECT PROPER SET
    1 DO 2 I=1,NO
      IF(NYMD.NE.LYMD(I)) GO TO 2
      IF(ABS(ALAT(I)-FLAT).GT.TBL) GO TO 2
      IF(ABS(ALON(I)-FLON).GT.TBL) GO TO 2
      GO TO 6
    2 CONTINUE
      NR=NR+1
      IF(NR.GT.NO) NR=1
    3 READ(UTP)        LYMD(NR),ALAT(NR),ALON(NR),FLXD(NR),((IFH(L,LL,NR)
     *,L=1,14),LL=1,25)
      IF(EOF,UTP) 4,1
    4 REWIND UTP
      IFLAG=IFLAG+1
      IF(IFLAG.LE.1) GO TO 3
      WRITE(6,5)
    5 FORMAT( 63H *** FOF2-HM TABLES FOR THIS STATION AND DATE NOT FOUND
     * IN FILE)
      IYR  = -1
      RETURN
    6 FLUX=FLXD(I)
C
C         FORM AZIMUTH AZ, EARTH CENTRAL ANGLE STATION TO SAT. ECA,
C         IONOSPHERIC LAT.,LON. OLAT,OLON, MAGNETIC LAT. OF ION. POINT
C         HLAT, AND LOCAL TIME TLOC
      IF(AZ.LT.Q0) AZ=AZ+PI2
      SLAT= SIN(FLAT)
      CLAT= COS(FLAT)
      SEL= SIN(ELEV)
      CEL= COS(ELEV)
      SAZ= SIN(AZ)
      CAZ= COS(AZ)
      SF=R*CEL/RM
      CF= SQRT(Q1-SF*SF)
      SA = CEL * CF - SEL * SF
      CA = SEL * CF + CEL * SF
      ECA= ATAN(SA/CA)/DR
      SNLAT=SLAT*CA+CLAT*SA*CAZ
      CNLAT= SQRT(Q1-SNLAT*SNLAT)
      OLAT= ATAN(SNLAT/CNLAT)
      SDLON=SAZ*SA/CNLAT
      CDLON= SQRT(Q1-SDLON*SDLON)
      OLON=FLON+ ATAN(SDLON/CDLON)
      SML = SNLAT * SPLAT + CNLAT * CPLAT *  COS( OLON-PLON)
      CML= SQRT(Q1-SML*SML)
      HLAT= ATAN(SML/CML)
      TLOC=TIME+OLON+PI2
```

```
      TLOC=AMOD(TLOC,PI2)
      TLOCAL=TLOC/HR
C
C        INTERPOLATE FOF2-HM TABLES
C        COMPUTE INDICES LT1,LT2, INCREMENT DLT FOR LOCAL TIME INTERPOL.
      XLT=TLOCAL/Q2+Q1
      LT1=XLT
      DLT=LT1
      DLT=XLT-DLT
      IF(XLT.GE.Q3P5) LT1=LT1+1
      IF(XLT.GE.Q4P5) LT1=LT1+1
      IF(LT1.LT.3.OR.LT1.GT.6) GO TO 10
      DLT=DLT*Q2
      IF(DLT.GE.Q1) DLT=DLT-Q1
   10 IF(LT1.GT.14) LT1=1
      LT2=LT1+1
      IF(LT2.GT.14) LT2=1
C
C        COMPUTE EARTH CENTRAL ANGLE INDEX IALF, INCREMENT DALF
      ALF=ECA/Q7+Q1
      IALF=ALF
      IF(IALF.GT.4) IALF=4
      DALF=ALF- FLOAT(IALF)
      KI=1
C
C        COMPUTE AZIMUTH INDICES MP1,MP2, INCREMENT DELAZ
   20 NAZ=JAZ(IALF)
      MP1=KAZ(IALF)
      IF(MP1.GT.1) GO TO 30
      DELAZ=Q0
      MP2=1
      GO TO 60
   30 DAZIM=PI2/ FLOAT(NAZ)
      AZIM=Q0
      DO 40 LOOP=1,NAZ
      MP2=MP1
      MP1=MP1+1
      IF(LOOP.EQ.NAZ) MP1=MP1-NAZ
      AZIM=AZIM+DAZIM
      IF(AZIM.GE.AZ) GO TO 50
   40 CONTINUE
   50 DELAZ=(AZIM-AZ)/DAZIM
   60 CONTINUE
C
C        INTERPOLATE IN TIME FOR PROPER POINTS MP1,MP2 TO GET FI,HI
      DO 80 IPT=1,2
      MPT=MP(IPT)
      DO 70 L=1,2
      LTM=LT(L)
      IH1=IFH(LTM,MPT,I)/10000
      HT(L)= FLOAT(IH1)*Q100
      IF1=IFH(LTM,MPT,I)-IH1*10000
   70 FT(L)= FLOAT(IF1)/Q100
```

```
      FI(IPT)=FT(1)+(FT(2)-FT(1))*DLT
   80 HI(IPT)=HT(1)+(HT(2)-HT(1))*DLT
C
C         INTERPOLATE IN AZIMUTH TO GET FA,HA
      FA(K1)=FI(1)+(FI(2)-FI(1))*DELAZ
      HA(K1)=HI(1)+(HI(2)-HI(1))*DELAZ
      IF(K1.EQ.2) GO TO 100
      K1=2
      IALF=IALF+1
      IF(IALF.GT.4) GO TO 90
      GO TO 20
   90 FA(2)=FA(1)
      HA(2)=HA(1)
C
C         INTERPOLATE IN EARTH CENTRAL ANGLE TO GET FOF2,HM
  100 FOF2=FA(1)+(FA(2)-FA(1))*DALF
      HM=HA(1)+(HA(2)-HA(1))*DALF
C
C         COMPUTE SECOND PART OF PROFILE
      CALL PROFL2(OLAT,OLON,HS,TIME,IDAY,MON,FLUX,FOF2,HM,HLAT,
     *            YM,YT,XK,RRM,XNTNM)
      IF(XNTNM.LE.20) GO TO 140
C
C         COMPUTE ELEVATION ANGLE CORRECTION DELEV
      FRAT=(FOF2/FB)**2
      CALL BETA(FRAT,XNTNM,HS,HM,YM,SEL,CEL,DELEV)
C
C         COMPUTE VERTICAL AND ANGULAR ELECTRON CONTENT TOTN,TOTNA
C         COMPUTE RANGE CORRECTION DRANG
      RAT=(R/(R+ HM))**2
      DEN2=Q1-RAT*CEL*CEL
      DEN= SQRT(DEN2)
      TOTN=XNTNM*QNM*FOF2**2
      TOTNA=TOTN/DEN
      DRANG=FRAT*RN3*XNTNM/DEN
C
C         COMPUTE RANGE RATE CORRECTION DRATE
      DRATE=DRANG*EDOT*RAT*SEL*CEL/DEN2
      DRATE=DRATE-FRAT*RN3*HDOT*RRM/DEN
  140 CONTINUE
      RETURN
      END
```